Essays on Sustainable Development

A thesis submitted to the School of Economics of the University of East Anglia (UEA) in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Abstract

The overlaps and interactions between social, environmental, and economic considerations, being the three pillars of sustainable development, can have important implications and pose peculiar challenges for the policy and management of development strategies, especially for developing countries. However, existing empirical works do not usually investigate the links among these three pillars simultaneously. Among these convoluted links, the link between health and economic performance and the way environmental degradation affects this link, particularly stands out. This work consists of three studies. In the first study, we develop a simultaneous system of equations in order to analyze the association between environmental degradation, represented by ambient fine particulate matter ($PM_{2.5}$) air pollution, poor health in terms of the burden of non-communicable diseases attributable to ambient $PM_{2.5}$ air pollution, and economic performance. Our findings suggest that air pollution significantly contributes to the slowing down of economic performance in many countries through its impact on health, and that efforts to reduce air pollution through policy intervention can result in great social and economic benefits. In the second study we also use a system of simultaneous equations in order to study the driving forces of environmental degradation in Egypt and the way they affect the country's chances for sustaining development. Our findings highlight the role of population growth as a major driving force of environmental degradation in Egypt, which adversely affects public health, consequently lowering labour productivity. In the third study, we report the results of a contingent valuation (CV) survey we conducted in Egypt in order to estimate the economic value of air quality and the value of reducing the health risks associated with ambient $PM_{2.5}$ air pollution, which represent key inputs into the estimation of the benefits and costs of air pollution mitigation strategies and policies.

Dedicated to the memory of my wonderful and deeply missed mother:

Sohair Morsy Youssef, May 12, 1944 – April 14, 2021

“When a mother dies, a daughter's mourning never completely ends”

Hope Edelman, Motherless Daughters.

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“She realized that she belonged among the weak, in the camp of the weak, in the country of the weak”
“She was like her country, which stuttered, gasped for breath, could not speak”

Milan Kundera, The Unbearable Lightness of Being.

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List of Abbreviations

2SLS	Two Stages Least Square
3SLS	Three Stages Least Square
ALO	Arab Labour organization
ALRI	Acute lower respiratory infections
AQG	The WHO air quality guidelines
ASR	Adult Survival Rate
BT	Brander–Taylor model
CAAA	Clean Air Act Amendments
CAPMAS	Egyptian Central Agency for Public Mobilization and Statistics
CDF	Cumulative Distribution Function
CEE	Central and Eastern Europe
CEMAC	Economic and Monetary Community of Central Africa
CIESIN	Centre for International Earth Science Information Network
COI	The Cost of Illness
COPD	Chronic obstructive pulmonary disease
CRD	Chronic Respiratory Diseases
CVD	Chronic Cardiovascular Diseases
CVM	Contingent Valuation Method
DALYs	Disability-Adjusted Life Years
DW	Durbin-Watson statistic
EEAA	The Egyptian Environmental Affairs Agency

EKC	Environmental Kuznets Curve
EPA	Environmental Protection Agency
EPI	Environmental Performance Index
FAOSTAT	Food and Agriculture Organization of the United Nations
FE	Fixed Effects
GBD	Global Burden of Disease
GDP	Gross Domestic Product
GHG	Green House Gases
GMAPS	Global Model of Ambient Particulates
GMM	The Generalized Method of Moments
GNP	Green National Product
GS	Genuine Savings
HANDY	Human and Nature Dynamical model
HSDI	Human Sustainable Development Index
ICPD	International Conference on Population and Development
IHD	Ischemic heart disease
ILO	International Labour Organization
IPAT	Impact, Population, Affluence, and Technology model
IUCN	International Union for the Conservation of Nature
IV	Instrumental Variables
LDCs	Least Developed Countries
MEM	Multi-Equations Models
ML	The Maximum Likelihood method

MRW	Augmented Solow model or Mankiw, Romer and Weil Model
NCDs	Noncommunicable Diseases
NICHP	Egyptian National Information Center for Health and Population
NOAA	National Oceanic and Atmospheric Administration
NSDS	National Sustainable Development Strategy
OECD	Organization for Economic Co-Operation and Development
OLS	Ordinary Least Square
PDE	Population- Development- Environment model
P-E	Population-Environment
PEDA	Population- Environment- Development- Agriculture model
PPP	Purchasing Power Parity
PWT	Penn World Tables
QALYs	Quality Adjusted Life Years score
RE	Random Effects
RUM	Random Utility Maximization
SDGs	Sustainable Development Goals
SEM	Single Equation Models
SL	Sustainable Livelihoods approach
STIRPAT	Stochastic Impacts, Population, Affluence and Technology model
SUR	Seemingly Unrelated Regression
TED	Conference Board Total Economy Database
TFP	Total Factor Productivity

TFR	Total Fertility Rate
UN	United Nations
UNCHE	The United Nations Conference on the Human Environment
UNCSD	The United Nations Conference on Sustainable Development
UNDP	United Nations Development Program
UNEP	The United Nations Environment Program
UNFCCC	The United Nations Framework Convention on Climate Change
VAT	Value Added Tax
VCM	Vicious Circle Model
VSL	Value of Statistical Life
WDI	World Development Indicator
WHO	The World Health Organization
WTA	Willingness to Accept
WTP	Willingness to Pay
WTS	Willingness to Support
YCELP	Yale Centre for Environmental Law and Policy
YLD	Years Lost due to Disability
YLL	Years of Life Lost

Introduction

Health is one of the keys to sustainable development and is a precondition for achieving sustainability, also it is an outcome and an indicator of all the three aspects of sustainable development (social, environmental, and economic)[1]. Besides its direct and immediate effect on human wellbeing, health can influence the output level of a country via various channels. The first is its direct effect on labour productivity. Better health reduces workforce incapacity, infirmity, and is a key factor in improving the level of education, through increasing school attendance and enhancing scholastic performance. Furthermore, a healthier and a more educated workforce is more capable of creating, using, and adapting new technologies, which makes them more productive and increases their opportunities of obtaining higher returns. The second channel is the incentive effect, which is based on the idea that healthier individuals have a greater life expectancy, thus they have the incentive to increase their investments especially in education, which in turn contributes to both human and physical capital accumulation processes, and helps in maintaining a state of continuous growth. Another economic impact of good health is reducing healthcare expenditures, thus freeing some of the resources used for healthcare towards alternative uses.

On the other hand, illness and disability have noteworthy adverse economic impacts. Poor health substantially reduces productivity, and increases the number of days lost due to sickness absence, with the consequences being particularly severe in developing countries, where a higher fraction of workers is engaged in manual labour, and where social security provisions and health care services are limited compared with developed countries. Therefore, health problems can manifest as a reduction and an obstacle to economic growth, and hence to the sustainability of development in developing countries.

Noncommunicable Diseases (NCDs) have been emphasized as one of the major health problems that represents a serious challenge for sustainability. Reducing the number of people suffering from NCDs has recently been added to the Sustainable Development Goals (SDGs) in the United Nations (UN) 2030 Agenda for Sustainable Development (target 3.4). The 2030 Agenda for Sustainable Development also emphasized that the SDGs cannot be achieved when there is high prevalence of debilitating diseases, and that human health cannot be maintained without improving environmental quality, especially air quality. Therefore, tackling air pollution is crucial to achieving the SDGs.

[1] This idea has been emphasized in the UNCSD, known as the Earth Summit, which was held at Rio de Janeiro, Brazil on 20-22 June 2012, in its outcome document titled "*The future we want*".

The World Health Organization (WHO) data reveals that NCDs kill more than 40 million persons every year, thus accounting for nearly 70% of all global deaths. Among these deaths, about 38% afflict people aged 30-69, and 80% occur in lower-middle and low-income countries. The NCDs and sustainable development are connected in various ways, apart from their direct impact on the quality of life, increases in NCDs pose substantial economic risks, as the costs of treating NCDs are enormous, both at the macro and the micro economic levels. A study by the World Economic Forum and the Harvard School of Public Health in 2011, predicted that by 2030, the economic burden of NCDs will exceed US$ 30 trillion, which represents nearly 48% of the global Gross Domestic Product (GDP) in 2010, and thus would result in pushing millions of people below the poverty line, and in keeping many countries from escaping the poverty trap (Bloom et al., 2012).

Furthermore, although NCDs represent a continuous fiscal burden for all countries, they have particularly significant economic implications in least developed and developing ones, where NCDs mostly affect people in their productive age, when they are at the peak of their working lives, and are supporting their families, in contrary to the case of developed countries[2] (WHO, 2017). Therefore, the governments of developing countries are confronted by the challenge of how to increase public spending on healthcare and social protection systems, while facing a reduction in the governmental revenues resulting from the inability of many people to work during their productive age because of ill health.

Ambient air pollution is the second leading cause of deaths from NCDs worldwide (WHO, 2019). The highest levels of air pollution are experienced in developing countries, which consequently bear the heaviest toll of diseases attributed to it, where more than 90% of air pollution-related diseases occur in low and middle-income countries, mostly in Asia and in Africa. The WHO data reveals that ambient air pollution alone was responsible for 19% of all deaths due to cardiovascular diseases worldwide in 2015. Also, in 2017, ambient air pollution was responsible for about one third of deaths from the leading NCDs (lung cancer, strokes, ischemic heart disease, chronic obstructive pulmonary disease, and respiratory diseases), where these accounted for approximately 4.2 million premature deaths. The mortality due to lung cancer increased significantly from 23% in 2015 to 29% of all deaths attributable to NCDs in 2017. At the same period, mortality from strokes increased from 21% to 24% of all deaths due to NCDs, while mortality from ischemic heart disease due to ambient air pollution increased from 24% to 25% of all NCDs deaths. Projections indicate that in the absence of effective air pollution control measures, ambient air pollution will cause between 6 and 9 million deaths per year by the year 2060.

[2] The WHO's reports indicate that nearly 30% of NCD-related deaths in low and low-middle income countries occur under the age of 60, whereas in high-income countries the proportion is only 13%.

The World Bank data indicate that in 2015, global economic losses which can be directly traced back to ambient air pollution, as represented by the lost economic productivity resulting from pollution-related diseases and premature deaths, is estimated to be US$ 225 billion, along with an increase by about US$ 21 billion in medical expenditures, in addition to the cost resulting from the negative impact of air pollution on both agricultural crops production and infrastructure.

In light of the considerations above, an assessment of the linkages between environmental degradation and unhealthy conditions, which can hinder the accumulation of both human and physical capital in the context of economic development, is necessary in order to fill the gaps in knowledge about the trade-offs between aspects of sustainability, and the challenges posed by such trade-offs to policy makers in formulating critical decisions. Therefore, in order to explore the interconnections and linkages between the pillars of sustainable development, we suggest a framework for simultaneously analyzing the three empirical relationships between environment-economic growth, health-economic activity, and environment-health. We mainly focus on exploring the extent to which ambient particulate matter (PM)[3] air pollution, as an example of deteriorating environmental conditions, contributes to poor health and poor quality of life, in terms of mortality and morbidity due to NCDs, and the way this interaction between human health and the environment affects long-term economic growth, with particular reference to Egyptian economy as an example.

Our review of empirical literature on the environment and economic growth shows that just a few studies have paid attention to the impact of fine particulate matter ($PM_{2.5}$) air pollution on economic performance via the health channel, and that none of these have employed a simultaneous approach in their analysis. In addition, although the global economic burden of NCDs attributable to $PM_{2.5}$ air pollution has gained attention in the past few years, there exists only a few empirical studies about it, and almost none of these empirical works on health and economic growth have emphasized mortality and morbidity due to NCDs attributable to ambient $PM_{2.5}$ air pollution as an indicator of the poor health linked to air pollution.

In this study we tackle some of these shortcomings in the literature, first by employing a more suitable analytical approach that relies on a simultaneous system of equations, which enables the identification of both the direct effect of environmental degradation on economic performance, along with its indirect impact via the health channel, and second by focusing on mortality and morbidity due to NCDs attributable to ambient $PM_{2.5}$ air pollution, which is a more appropriate indicator for measuring the health

[3] PM is usually measured in two size ranges: PM_{10} and $PM_{2.5}$, where PM_{10} indicates the concentration of particles with diameters less than or equal to 10 microns in size. $PM_{2.5}$, also called "fine particulates", refers to the concentration of particles with diameters less than or equal to 2.5 microns in size. $PM_{2.5}$ is more indicative of serious health concern than PM_{10}, since smaller particles can travel deeper into the lungs and thus can cause more harmful health effects.

burden of air pollution. In addition, we conduct a specific case study of Egypt, which is the top country worldwide with respect to the health burden attributable to ambient $PM_{2.5}$ air pollution, and despite this, very limited research has been conducted on the economic burden of NCDs and both the economic and health burdens of $PM_{2.5}$ air pollution neither from the macro- nor the micro-economic perspectives.

In the next section, we illustrate the major global trends and patterns in air pollution, NCDs, and per capita income across countries since 1990, with special focus on $PM_{2.5}$ air pollution, and the burden of disease from air pollution, as represented by Disability Adjusted Life Years (DALYs) due to ambient PM air pollution.

Air Pollution

An increase in ambient air pollution around the world has been driven by the rapid urbanization and the expansion of megacities, industrialization and globalization of production, widespread usage of pesticides and toxic chemicals in agricultural production, and the growing use of motor vehicles. The impact of air pollution on human health may differ depending on pollutant constituents. PM air pollution has been found to be related to the most serious health impacts, especially chronic conditions and mortality from lung cancer, and cardiovascular and respiratory diseases.

Fine particulate matter air pollution concentration and exposure

Emissions from industrial production, motor vehicles, and coal-burning power plants are the main sources of $PM_{2.5}$ air pollution. The relative importance of these sources to $PM_{2.5}$ concentrations may vary within and between countries and regions. The major sources of $PM_{2.5}$ in China, for example, are the industrial and power plant burning of coal and other fuels, transportation, and open burning of agricultural waste. Meanwhile, in India $PM_{2.5}$ comes mainly from the construction industry, brick production, transportation, industrial and power plant burning of coal, and diesel-powered equipment. In addition, the relative contributions of various sources to the global $PM_{2.5}$ are changing over time, as a number of countries have restricted some of their activities in order to reduce air pollution, while others have increased their reliance on the activities causing air pollution. Understanding the drivers behind high $PM_{2.5}$ levels may reveal valuable insights about the impact of the efforts to improve air quality.

The WHO's latest data indicates that the vast majority of the world's population lives in areas with unhealthy concentrations of air pollutants. Although many countries have witnessed some improvements in air quality during the past few decades, these changes have been uneven across countries. Over a period of 27 years, particularly from 1990 to 2017, there was a slight decrease, from 96% to 92%, in the percentage of the world's population living in areas where the WHO's strictest air quality guideline[4] (10 μg/m³ $PM_{2.5}$) is exceeded. This slight decrease has been driven by decreases in a few of the most populous countries such as the United States and Brazil.

In the United States, the percentage of people living in areas exceeding the WHO guideline for $PM_{2.5}$ decreased gradually from 50% in 1990 to nearly 40% in 2010, and then dropped to around 3% in 2017. In Brazil, there was a steady increase in the percentage of population exposed to high levels of $PM_{2.5}$ until 2010, then over the next seven years this percentage declined by nearly 23%, reaching 68% of the population in 2017. At the same time, some other countries such as Japan and the European Union member countries, have also experienced reductions in $PM_{2.5}$ exposure, mostly since 2010, yet they still have more than 80% of their populations living in areas where the exposure is above the WHO recommended guideline. The proportion of population living in areas above the strictest guideline in the remaining countries ranged from 92% to 100%.

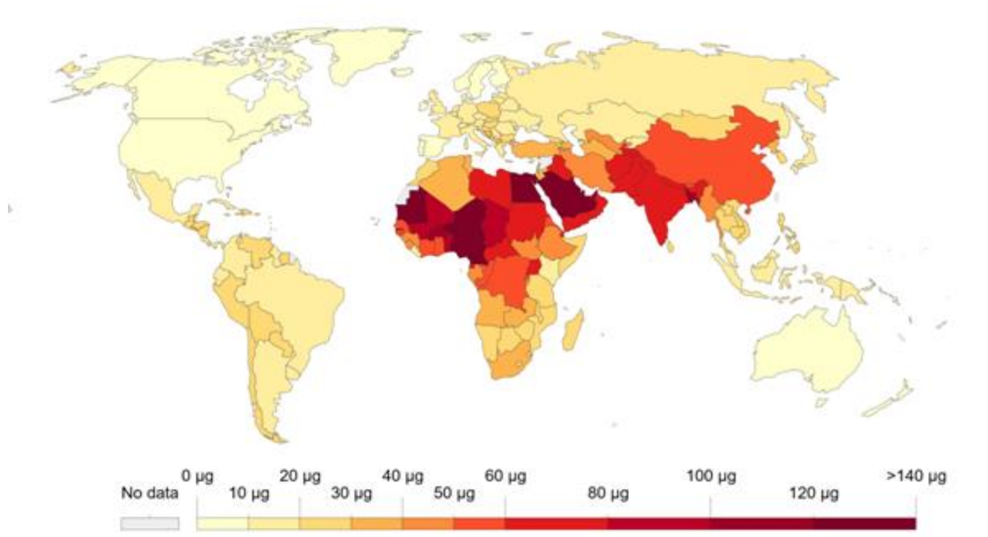

Figure (I.1): World distribution of $PM_{2.5}$ air pollution mean annual exposure (in micrograms per cubic meter) in 2016. Source: World Bank database.

On the other hand, the data shows that over the period between 1990 to 2017, nearly 67% of the world population were living in areas where exposure levels exceed 25 μg/m³ $PM_{2.5}$, and 82% were living in areas where levels exceed 15 μg/m³ $PM_{2.5}$, while the percentage of population living in areas that fail to

[4] The WHO air quality guidelines (AQG) and interim targets for annual mean concentrations of PM are: Air quality guideline (10 μg/m³), Interim target-1 (35 μg/m³), Interim target-2 (25 μg/m³), and Interim target-3 (15 μg/m³) (WHO, 2006).

meet even the least strict target (35 μg/m^3$PM_{2.5}$) remained steady at around 54%. As Figure (I.1) illustrates, in 2016 the annual exposures to $PM_{2.5}$ was highest in North Africa and Middle Eastern countries, such as Saudi Arabia, Egypt, and Iraq. South Asian countries like India, Bangladesh, and Pakistan have also experienced similarly high levels of exposure to $PM_{2.5}$. Meanwhile, the United States, Norway, Canada, and Sweden, were among the 10 countries with the lowest $PM_{2.5}$ exposure levels.

NCDs

As shown in Figure (I.2), the number of Years of Life Lost (YLLs) due to NCDs in developing countries is greater than its counterpart in the developed ones. That can be explained by the fact that NCDs tend to kill people at a younger age in developing countries, while these diseases affect people in developed countries mainly near the end of their lives (WHO, 2010c). The high social and economic consequences of these deaths in developing countries represent a compelling argument for the need to increase the investment in preventing NCDs. Bloom et al (2012) indicated that the greatest burden of cardiovascular disease prevalence is experienced in both low and middle-income countries, and that it is estimated that by 2030, deaths attributable to NCDs, as a portion of total deaths, are expected to rise by 1%, 12%, and 45% in high, middle, and low-income countries respectively. Also, it is projected that by 2030, the prevalence of NCDs within the sector of population at productive age (15-59 years), will decrease in high income countries by 5%, while it is expected to increase in middle- and low-income countries by 12% and 32%, respectively (Nikolic et al., 2011).

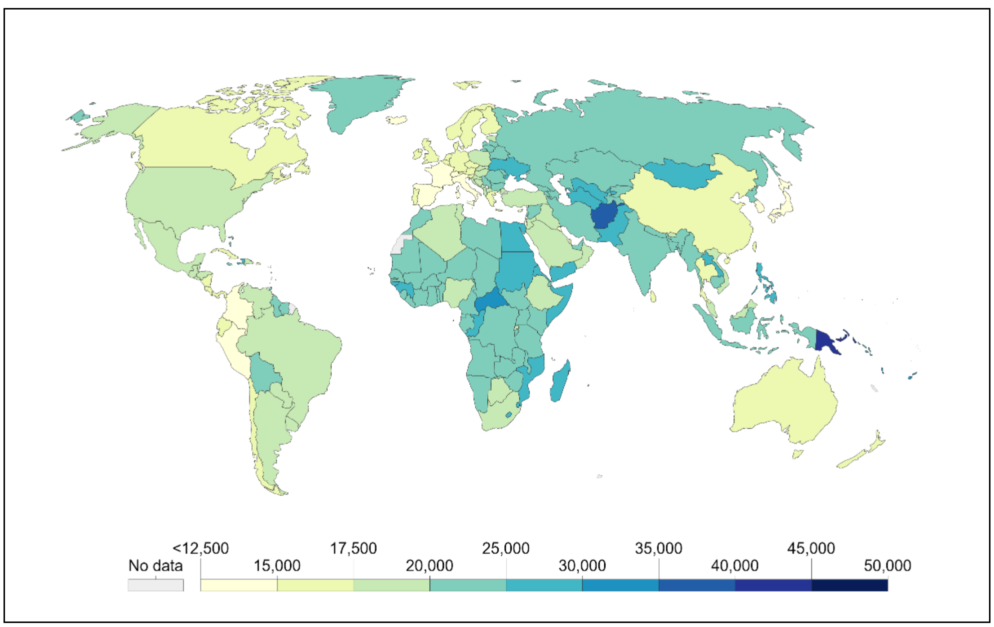

Figure (I.2): World distribution of DALYs due to NCDs in 2017. Source: Institute for Health Metrics and Evaluation (IHME), Global Burden of Diseases.

Estimates of the economic burden of NCDs at the country level provide insights on the scale of the problem. For example, it has been estimated that NCDs in Egypt are leading to an overall production loss of 12% of the country's GDP, also the probability of being employed for people suffering from NCDs is lower than the average by about 25 percentage points (Rocco et al., 2011).

Burden of disease from fine particulate matter air pollution

The burden of disease is a summary measure of the quantitative impact of ill health conditions of individuals, in terms of both premature mortality and disability, and can provide comparable and consistent information on the impact attributable to a specific disease, on both the country and global levels. Therefore, the burden of diseases is a vital measure for informing health policy and planning. The DALY is a common indicator of the burden of diseases. It refers to a lost healthy life year, whether due to premature death or because of some degree of disability (physical or mental) within a specific period of time. In other words, the DALY is a negative concept that measures the gap between the current health status of a population and some reference ideal point. This indicator can assist in identifying disadvantaged groups, in prioritizing health care systems, and optimizing targets of health interventions, which can increase the allocative efficiency of the health care sector. In addition, as a comparable measure of output for an intervention, reductions in expected DALYs can be used to quantify the benefits of interventions for cost-effectiveness analysis.

As mentioned earlier, air pollution is one of the leading environmental risk factors, where many studies have documented the wide range of health impacts of exposure to air pollution. Some of these effects occur due to short-term exposure, while others result from exposure to air pollution over longer time periods. The WHO data indicates that in 2017 air pollution in terms of ambient $PM_{2.5}$, household air pollution, and ozone have all contributed to nearly 4.9 million deaths, which represented about 8.7% of all global deaths, and approximately 147 million years of healthy life lost, which amounted to 5.9% of global DALYs, and that China and India had the highest mortality burden with about 1.2 million deaths attributed to air pollution in each of them. In its assessment of the Global Burden of Disease (GBD), the WHO emphasized that there is a causal relationship between exposure to ambient $PM_{2.5}$ and a wide range of diseases, where exposure to high average concentrations of $PM_{2.5}$ is found to be the most consistent and robust predictor of mortality from cardiovascular and respiratory diseases, and lung cancer. The data shows that people in the less developed countries are exposed to $PM_{2.5}$ levels four to five times higher than those of the more developed countries, which indicates a strong inverse relationship between $PM_{2.5}$ exposure and the country's level of social and economic development.

Figure (I.3) shows that in 2016, Egypt have had the highest burden of DALYs due to $PM_{2.5}$ air pollution. In 2017, exposure to ambient $PM_{2.5}$ accounted for 2.9 million deaths and a loss of 83 million DALYs, which means that $PM_{2.5}$ exposure is responsible by itself for about 5.2% of all global deaths and nearly 3.3% of all global DALYs. The burden of $PM_{2.5}$ was concentrated in China and India, which are the two most populous countries, where figures show that $PM_{2.5}$ exposure in these two countries is responsible for about 52% of the total global deaths and 50% of the DALYs due to exposure to $PM_{2.5}$.

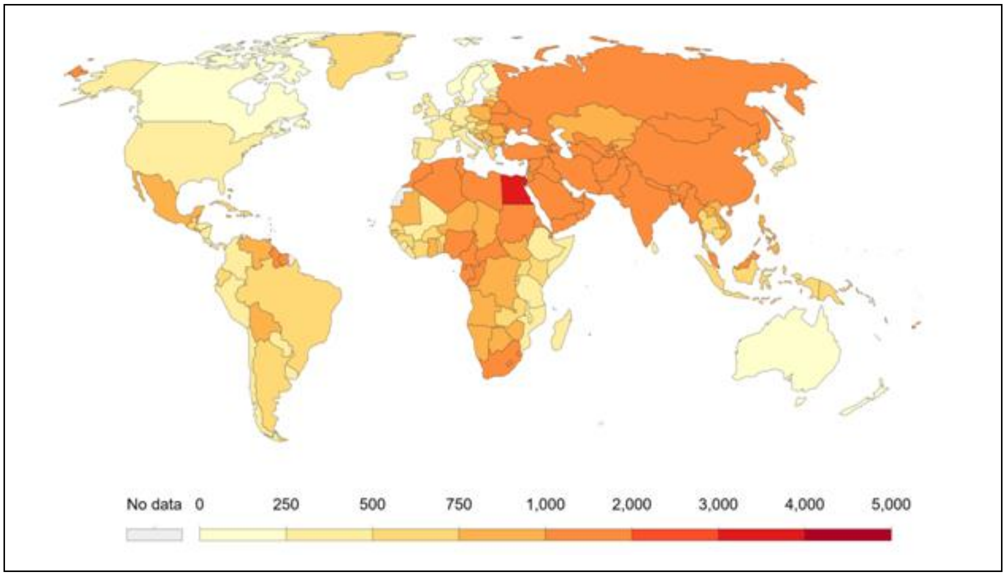

Figure (I.3): World distribution of DALYs due to PM air pollution in 2016. Source: Institute for Health Metrics and Evaluation (IHME), Global Burden of Diseases.

The health burden from ambient $PM_{2.5}$ exposure has increased during the past few decades. During the period from 1990 to 2017, the number of deaths attributable to $PM_{2.5}$ exposure has increased by almost 68%. It is worth mentioning that exposure to high levels of ambient $PM_{2.5}$ is one of the major contributors to the decrease in life expectancy around the world. It has been estimated that in 2016, exposure to ambient $PM_{2.5}$ have reduced life expectancy by an average of 19 months in South Asia and 15 months in both North Africa and the Middle East, while this impact was far lower in the more developed countries, as it is estimated to be about 4.5 months, on average, in the high-income regions of North America and Asia Pacific.

GDP Per Capita

Figure (I.4) shows GDP per capita, measured in international US$ in 2011 prices (such as to adjust for price changes over time and price differences between countries). The figure illustrates the income gap between rich and poor countries. That gap continues to widen, where it reached more than US$ 65.000 in

2017, compared with US$ 35.700 in 2010. In 2018, the world average GDP per capita was $11.296, where the top countries in terms of GDP per capita included Monaco (US$ 166.726), Luxembourg (US$ 144.340), Switzerland (US$ 82.838), Norway (US$ 81.807), Iceland (US$ 73.191), Qatar (US$ 69.026), and Singapore (US$ 64.581). On the other hand, Benin (US$ 902), Burkina Faso (US$ 731), Congo (US$ 561.8), Afghanistan (US$ 520), Madagascar (US$ 460), Malawi (US$ 389.48), and Burundi (US$ 275.4) were among the lowest 10 countries with respect to GDP per capita.

According to World Bank data, global per capita GDP grew by an annual average of 1.88% during the period from 1961 to 2017. Meanwhile, the global economy expanded at an annual average of 3.52% over the same period. During the 1990s of the past century, oil-rich countries such as Iraq and Kuwait had the highest increases in per capita GDP around the world. In 2018, about 34 countries have experienced negative growth in their per capita GDP, where Equatorial Guinea (-6.43%), Angola (-5.28%), Nicaragua (-5%), Yemen (-4.9%), and Sudan (-4.6%) have witnessed the highest declines in per capita GDP growth rates. Some other developing economies such as China, Vietnam, and India have achieved per capita GDP growth rates well above the global average, (6.11%), (6.6%), and (6%) respectively.

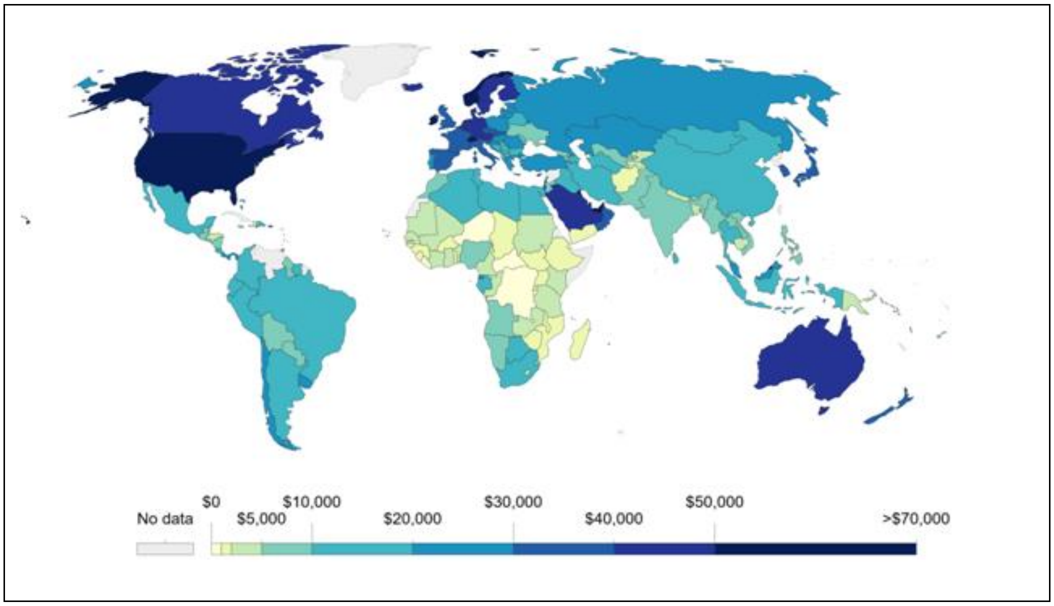

Figure (I.4): World distribution of GDP per capita, illustrating the income gap between rich and poor countries continues. Source: World Bank database.

After illustrating those main trends of the social, environmental and economic variables of interest, in the next section, we will introduce a brief overview of the conceptual framework of sustainable development, along with the different models and analytical approaches used to understand the various dimensions of sustainable development and the links between them. This section illuminates the importance of the overlap between human, environmental, and economic factors, being the three pillars of sustainability, and the deficient understanding of that problem in contemporary literature.

Sustainable Development Framework

The contradictions between the environment and development were first recognized in the United Nations Conference on the Human Environment (UNCHE) held in Stockholm 1972. This conference is regarded as the starting point of the global environmental movement, and the Stockholm Declaration grew into the main source for the establishment of environmental law. In 1980, the International Union for the Conservation of Nature (IUCN), in cooperation with both the United Nations Environment Program (UNEP) and the World Wide Fund for Nature, have developed the *"World Conservation Strategy",* which emphasized conservation as a mean to support development and to sustain the use of natural resources. This strategy is considered among the first official documents that establish the concept of sustainable development, which was coined as an expression for the first time by the Brundtland Commission in 1987. The subsequent years[5] have witnessed the evolution of sustainable development as a concept, a goal, and an essential movement towards a better common future.

Definition and Concept: the Brundtland Commission briefly defined the term *sustainable development* as the kind of development which meets the needs of the present without compromising the ability of future generations to meet their own needs. Thus, progressing towards sustainable development implies that the objectives of increasing economic efficiency and material wealth must take human and environmental objectives into account. Despite the evolution of the concept of sustainable development over time and the emergence of many definitions for it, yet all of these definitions still somehow stem from the original definition set in the Brundtland's report "*Our Common Future*" (WCED, 1987), and all of them admit that the most applicable method for sustaining the development and securing future generations' well-being is to ensure that the aggregate stock of both man-made and natural capital available to next generations is at least equal to the current aggregate stock (Atkinson et al., 2007).

[5] Over the years, many international agreements have been established to address sustainable development issues. For example, the Earth Summit in 1992, released a declaration of principles (the so-called "Agenda 21" or "Rio Declaration) of the procedures required to protect the environment while maintaining the economic development, it includes international agreements on climate change and biodiversity, and a statement of principles on forests. The Kyoto Protocol of 1997 is one of the most important international treaties in that regard, and is considered to be an extension to the 1992 UNFCCC which obligates member countries to reduce GHG emissions through reducing CO_2 emissions resulting from industrial activities, being the main contributor to GHG emissions. Subsequent international conferences on sustainable development, like the World Summit on Sustainable Development in Johannesburg 2002 (Rio+10), The United Nations Conference on Sustainable Development in Rio de Janeiro 2012 (Rio+20), and the United Nations Sustainable Development Summit in New York 2015, reaffirmed all the commitments to sustainable development. The Paris Agreement which has emerged from the 2015 United Nations Climate Change Conference (also called COP21 or CMP11) is considered to be the world's first comprehensive climate agreement and one of the most important steps towards a serious deceleration of climate change. During the COP21, the interlinkages between climate change and air pollution have been emphasized, and it has been indicated that the implementation of the Paris Agreement will help in combating air pollution as well.

According to ecological economics literature, sustainability requires maintaining a non-declining natural capital stock, both in quantity and in quality, which requires imposing some constraints on the economic growth path in order to take the ecological limits into consideration. Costanza and Daly (1992) and Noël and O'Connor (1998) indicated that the most serious constraint on the use of natural resources is that the wastes released from economic activities should be less than the environmental waste sink capacity, and that their threats on human health should be reduced to the lowest possible level.

Although sustainable development and sustainability are different concepts and have been analysed and interpreted in various ways within the ecological economics literature (Pezzey and Toman, 2002; Robinson, 2004), a wide variety of perspectives have emerged in order to understand the concept of sustainable development according to the so-called *sustainability position*. The four proposed positions rang from "very weak sustainability" to "very strong sustainability" positions[6] (Gibbs et al., 1998). The conflict between weak and strong sustainability, and the way to resolve this disagreement has received much attention in the ecological and development economics literature (Ayres et al., 2001). Some crucial debate concerning sustainable development has ensued about which conception of sustainability should be adopted, whether it is the strong or weak sustainability (Beckerman, 1994; Atkinson, 2009).

The main idea of weak sustainability is based on the Hartwick Rule[7] which has been introduced in 1977. This rule states that the amount of investment in produce-manufactured capital should be enough to offset the decline in the stocks of non-renewable resources, such as to keep either the total net capital investment constant, or the rate of change of total net capital wealth constant, which would imply a non-decreasing welfare (Pearce et al., 1996; Harris, 2000; Ekins, 2011; Evans et al., 2015). Weak sustainability approaches are built upon the assumption that there is perfect substitutability between natural capital and human-made capital. Accordingly, human welfare does not depend on a particular sort of capital, and there are no significant differences between various kinds of capital and the well-being they produce. (Gibbs et al., 1998; Noël and O'Connor, 1998; Neumayer, 2010; Neumayer, 2012). The only thing that matters within the weak sustainability framework is maintaining the total value of the aggregate stock of capital to be non-declining (Costanza and Daly, 1992; Solow, 1993; Altwegg et al., 2004; Atkinson et al., 2007).

[6] The very weak and the very strong sustainability positions have generally been considered in literature to be less presumable. According to the very weak sustainability concept, the role of the environment in producing output is relegated to providing natural resources and to serve as a sink for the waste produced by human activities. Meanwhile, the very strong sustainability position claims that natural capital cannot be substituted by human made capital, and that environmental resources cannot be depleted without an irreversible loss in social welfare.

[7] Dietz and Neumayer (2007) pointed out that the idea of weak sustainability was implicitly established in the 1970s of the past century, in Hartwick-Solow models. These models developed the neoclassical theory of economic growth and extended it to take into account non-renewable natural resources as a factor of production. Also, they imputed both renewable and non-renewable natural resources into Cobb-Douglas production function, which have a constant and unitary elasticity of substitution between factors of production. This implies that natural capital and manufactured or produced capital could easily be substituted for each other.

Weak sustainability approaches have been subject to much debate. The main argument against weak sustainability approaches is their attitude regarding environmental problems (Gibbs et al., 1998). Although these approaches assume that environmental issues are the first concern in economic policy, they do not take into consideration the consequences of environmental degradation on the sustainability of human capital, which is a key determinant of the development process. Also, these approaches do not identify a holistic environmental policy, in which the required level of environmental quality is determined and the environmental risks to health are addressed. Atkinson et al (2007) indicated that the assumption of perfect substitutability between the different forms of capital is not realistic, since manufactured capital and natural capital are considered to be fundamentally complementary, and can only be interchanged marginally (Costanza and Daly, 1992; Rees and Wackernagel, 1996; Harris, 2000; Ekins et al., 2003). Also, weak sustainability perspectives ignore referring to the cost of substitution between production factors or the hardships associated with it, as the society may have to make considerable sacrifices in order to obtain one extra unit of some form of capital. Furthermore, there are some forms of capital, such as human capital, which is non-substitutable, and also there are some environmental impacts which are irreversible and irreparable (Pearce and Atkinson, 1998; Ekins et al., 2003).

Strong sustainability approaches, on the other hand, reject the substitutability between forms of capital, and hence believe that every form of capital should be kept separately. Natural resources are considered a distinct and crucial factor of production, and that their depletion or degradation cannot be compensated for by increasing investment in other forms of capital (Noël and O'Connor, 1998; Atkinson et al., 2007; Neumayer, 2010; Ekins, 2011). Strong sustainability perspectives are then based on the presumption that the society cannot allow economic activities to result in a continuous environmental deterioration and thus pose health risk on human capital. Based on this, they identify the levels of environmental quality to be achieved (e.g. emission levels) and set them as priorities to economic policies (Gibbs et al., 1998), and as a necessary condition for achieving sustainable development (Noël and O'Connor, 1998). Ekins et al (2003) argued that the current dominant development model should be considered unsustainable because it leads to the depletion of some crucial, non-substitutable forms of capital, and causes some irreversible environmental and health damages.

It can be said that both sustainability approaches are associated with different points of view on the required level of policy intervention in the economic system that is necessary and sufficient for sustaining the development (Gibbs et al., 1998). The differentiation between the weak and strong versions of sustainability is an essential issue for policy makers, because the way in which sustainable development is defined and put into operation, largely shapes the relationship between the economic, social and the environmental aspects of sustainable development, and the way they should be integrated.

Dimensions and Models: a lot of models and approaches have been developed in order to understand the dimensions of sustainable development and the linkages between them[8]. The interrelationships between the main pillars of sustainable development can be illustrated by the next figure.

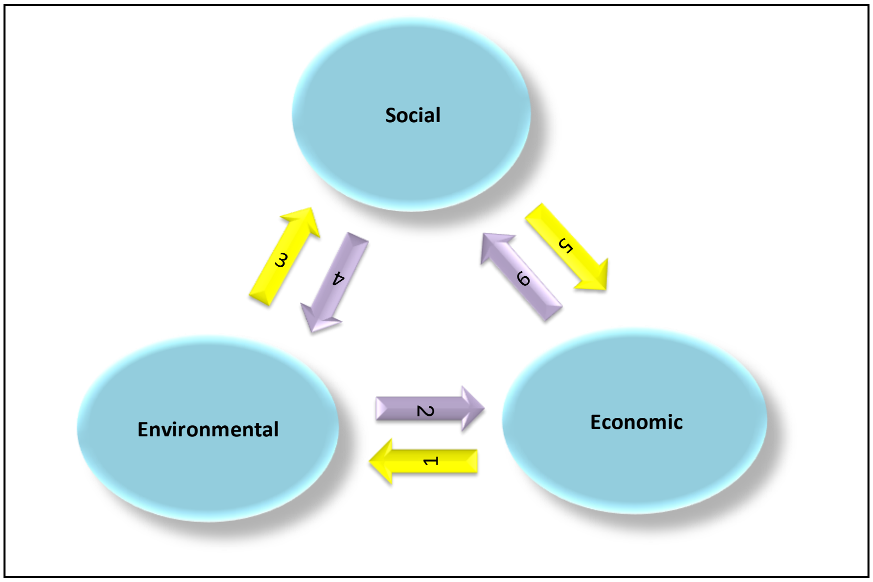

Figure (I.5): Interdependencies between Dimensions of Sustainable Development. Source: (OECD, 2005).

The first arrow refers to the impact of economic activities on the environment (e.g., depletion of natural resources, air and water pollution, climate change, deforestation, etc), or in other words, it represents the economic pressures on the environment. The second arrow represents the environmental or ecosystem services provided to the economy (e.g., raw materials, natural resources such as water, air, waste absorption, etc). The third arrow points out the environmental impacts on the society (e.g., impact of environmental degradation on health). The fourth arrow shows the influence of social variables on the environment (e.g., demographic changes such as population growth, gender and age distributions, urbanization, etc). The impact of social variables on the economy (e.g., labour productivity) is represented by the fifth arrow. Finally, the sixth arrow refers to the effects of economic activity on the society (e.g., income levels, wellbeing). This illustration stresses the necessity of understanding the linkages and trade-offs between economic, social, and environmental conditions in order to help policy makers in assessing the long-term consequences of current decisions, and in monitoring the progress of achieving sustainable development.

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[8] Such as the *Three Pillars Basic Model* or the *Triple Bottom Line* of sustainability (Altwegg et al., 2004), the *Prism of Sustainability Model* (Todorov and Marinova, 2009), and *the Egg of Sustainability Model* (Keiner, 2003, 2005).

Numerous different approaches have been devised in order to account for this multi-dimensional nature of sustainable development[9]. *Quantitative Models* have been frequently used in analyzing the dimensions of sustainable development, especially those models which are related to policy making perspectives[10,11].

In light of the previous discussion of the general framework of sustainable development, it can be said that sustainable development is a multi-dimensional phenomenon, which involves a set of relationships that explain the behaviour of numerous variables, where these variables indicate each of the aspects of sustainability. One step towards properly identifying the trade-offs between these aspects is to simultaneously analyze the reciprocal influences between them, because policy interventions that are based on better information about such trade-offs can help reduce any conflicts in the short-term, and mitigate any possible unintended consequences of these decisions and actions in the long-term. This becomes particularly important in the developing countries where the situation is rather complicated and the challenges and obstacles which these countries face in their pursuit of sustainable development are greater than those in the developed ones.

This thesis is divided into two parts. The first part explores the simultaneous interdependence between environmental degradation, health, and long-term economic growth. The central argument being that in assessing the links between aspects of sustainable development, there exists an issue of potential endogeneity among the variables of interest. One way to deal with this issue, which comprises the main contention of the first two empirical studies in this thesis (Chapters 2 and 3), is formulating the problem not as separate single equations, but as a system of simultaneous equations which jointly determine all the dependent variables[12]. In the framework of such joint system, the equations are inherently related because

[9] Classification of these models depends on many factors such as the theoretical starting point of the model and its conceptual perspective, the main purposes and objectives of the model, and the time scale and geographic area encompassed. With respect to the time factor, sustainability models can be divided into *Static Models* which aim to analyze and evaluate the current sustainability status, and *Dynamic Models* which aim to forecast or predict the process of sustainable development. Also, sustainable development models can be either *Global Models* or *Regional Models* which only apply on some local level. Finally, scale-related models are classified into *General* and *Specific* models, according to their composition and structure, such as *Physical Models, Conceptual Models,* and *Standardizing Models* (Todorov and Marinova, 2009).

[10] These include macro econometric models, computable general equilibrium models, optimization models, system dynamics models, probabilistic or Bayesian network models and multi-agent simulation models (Boulanger and Bréchet, 2005).

[11] Although sustainable development is a common concept, it is difficult to define strictly, and therefore it is difficult to have a single measure for it. A wide variety of indicator lists and descriptions have been produced using these models in order to measure countries' progress towards achieving sustainable development, such as the United Nations list of Indicators of Sustainable Development (United Nations, 2008; Evans et al., 2015), in addition to some other ongoing efforts to develop holistic indicators for measuring sustainability (Gerlagh et al., 2002; Parris and Kates, 2003; Nourry, 2008; Evans et al., 2015), such as the Ecological Footprint (EF) (Rees, 1996; Rees and Wackernagel, 1996), Green National Product (GNP) (Nourry, 2008), Genuine Savings (GS) (Pearce et al., 1996; Pearce and Atkinson, 1998), and the Human Sustainable Development Index (HSDI) (Neumayer, 2001; Bravo, 2013).

[12] Haavelmo (1943) was the first to notice that economic theorists have, in general, paid too little attention to the stochastic formulation of economic theories. In his influential paper "The Statistical Implications of a System of Simultaneous Equations" he indicated that the presence of error terms in economic relations results not only from statistical measurement errors, but also from the nature of economic behaviour, i.e. its dependence upon a greater number of factors than those which are explicitly accounted for in the theories, and therefore, a stochastic formulation is necessary in order to make such simplified relations elastic enough for realistic applications. He also indicated that a statistical

the contemporaneous errors associated with each dependent variable are correlated, which is a more reasonable assumption in analyzing the linkages and interactions between aspects of sustainable development[13].

Obtaining consistent and reliable estimates for the impact of air pollution on economic performance via its impact on health, represents a critical step in informing air quality policies and sustainability efforts. In addition to providing information on the macro level about the health and economic burden of air pollution, an effective policy intervention requires a better understanding of individuals' perceptions of air quality, or the trade-offs that people are willing to make in order to improve environmental quality, or reduce the health risks associated with air pollution, such that all the costs and benefits resulting from pollution reduction can be calculated. Thus, in the second part of this thesis we conduct a study from a microeconomic perspective in order to estimate the economic value of air quality and the value of reducing the health risks associated with ambient $PM_{2.5}$ air pollution in Egypt[14].

The structure of the rest of this thesis is as follows: Part (I) is titled "Environmental Degradation, Human Health and Long-Term Economic Growth". The main goal of this part is to analyse the role of health as a fundamental aspect of human capital, its role in achieving long-term economic growth, and the way environmental degradation affects these roles from a macroeconomics perspective. This part contains three chapters: Chapter (1), titled "Health and Economic Growth", introduces a brief summary of the evolution of the theories of economic growth, and a review of the theoretical literature on the relationship between economic growth and human capital. In addition, it demonstrates some examples of the different analytical approaches and assessment methods which have been used in dealing with health issues in economic growth models, in the context of both the neoclassical theory of exogenous growth and its extensions, and in the context of endogenous growth theories, along with discussing the strengths and limitations of each of these approaches. Finally, the last part of this chapter reviews some results from the empirical work on the links between health and economic growth. This chapter lays the theoretical

implication of assuming a system of such stochastic equations to be simultaneously fulfilled by the data is that estimating each of the equations separately becomes inadequate, due to the restrictions which the other equations impose upon the same variables.

[13] When comparing econometric models based upon the usual single regression equations with those based upon simultaneous equations, the coefficients provided by the joint estimation procedures have been found to be more efficient than those yielded by single equation estimation techniques (Haavelmo, 1943; Klein, 1960; Zellner, 1962; Zellner & Lee, 1995; Baltagi, 1998), because the joint estimation takes into account the cross-equation correlations of the error terms, and therefore it adds information on the error structure and thus improves efficiency.

[14] Egypt is a developing country, and it has been chosen as a case study due to a number of reasons: the first is that Egypt's economic development and industrialization policies, combined with weak environmental management and lack of environmental policies, especially those focusing on reducing emissions, have resulted in widespread and severe air pollution. The second reason is the particularly heavy toll of air pollution on public health in Egypt, as it ranks first worldwide in terms of deaths attributable to ambient $PM_{2.5}$ air pollution. The third reason is that almost 50% of the Egyptian labour force are outdoors workers and therefore are more vulnerable to the adverse health effects of air pollution. Finally, Egypt has limited natural resources, and it mainly relies on its human resources as a factor of production, thus achieving sustainable economic development in Egypt greatly depends on the quality of human capital in terms of health, education, and skills.

foundation for the next two chapters. Chapter (2), titled "Air Pollution, Health, and Long-Term Economic Growth: An Empirical Investigation", represents an empirical study of a panel dataset of 145 developed and developing countries. The goal of this study is to explore how environmental degradation impacts long-term economic growth, emphasizing the link between air pollution, in terms of ambient $PM_{2.5}$ concentration, and health, in terms of DALYs due to $PM_{2.5}$ air pollution as the main channel of transmission. In Chapter (3), we present a case study of Egypt using a time series analysis of the Egyptian Economy. That study is titled "The Relationship between Population and the Environment and its Impact on Sustainable Development in Egypt". Its aim is to investigate the impact of poor health attributable to environmental degradation on labour productivity in Egypt, where special attention is paid to the demographic factors which may have contributed to the current witnessed environmental degradation in Egypt. The study shows the extent to which environmental degradation has negatively affected public health in Egypt, and the subsequent negative effects on labour productivity, which hinder the state's ability to sustain development.

From a policy making perspective, estimating the economic value of improving air quality, along with the health benefits associated with it, at the micro level is a key input into the estimation of the benefits and costs of air pollution mitigation strategies and policies, which may enhance individuals' probability of survival. Therefore, the main goal of Part (II) of this thesis, titled "The Economic Value of Environmental Quality and Health Risk Reduction", is to explore the economic value of improving the environment and reducing the health risks associated with environmental degradation, in addition to the role of this valuation in environmental policy determination. This part includes two chapters: Chapter (4), titled "The Economic value of Environmental Quality and Health", introduces the theoretical framework for valuing environmental quality and health. It presents the economic theory of value, and methods of valuing changes in environmental quality and health risk, either based on the measurement of an impact (e.g., Dose-Response Functions), or based on human behaviour (e.g. Revealed and Stated Preference). The main focus of this chapter is the Stated Preference approach, especially the Contingent Valuation Method (CVM), where we discuss in detail the development of CVM in environmental economics, a consumer preference model through which CVM responses are to be interpreted, CVM merits and limitations, credibility and reliability issues, and sources of bias and the way to mitigate them. This chapter also discusses sampling and survey design techniques, and elicitation formats, in addition to some of the recent empirical CVM literature on measuring the economic value of air quality, and the concept of the Value of Statistical Life (VSL). Chapter (5), titled "Air pollution and Willingness to Pay for Health Risk Reductions in Egypt: A Contingent Valuation Survey of Greater Cairo and Alexandria Households", represents a case study of Egypt, where we estimate the economic value of improved air quality (or the implicit shadow price of air quality) and the value of mortality risk reduction in Egypt. This chapter demonstrates the current environmental problems and their associated burden of diseases, along with sources of environmental degradation, and environmental strategies that have been previously implemented in Egypt and the constraints they suffer. This study employs a CVM in order to estimate the willingness to pay (WTP) per household, and the corresponding VSL, for environmental improvements and for reducing the health risks associated with air pollution in the cities of Cairo and Alexandria. Another purpose of this study is to test the respondents' awareness of air pollution issues and their associated health risks, in addition to exploring the way the air pollution risk is perceived in Egypt. Finally, in the last chapter we provide a summary of the main conclusions drawn from our three empirical studies.

Part I

Environmental Degradation, Human Health and Long-Term Economic Growth

Chapter 1

Health and Economic Growth

1. Introduction

Health is a crucial aspect of human welfare and is strongly linked to long-term economic development. In the early days of economic growth theory, physical capital accumulation was considered as the engine for economic growth. Starting from the 1960s of the past century, labour quality in the form of human capital accumulation began to get recognition as one of the significant contributors to economic growth. However, the vast majority of theoretical and empirical works have narrowly identified human capital with education. It was only in the 1980s and 1990s when the literature began to shed light upon health as an essential element of human capital. Despite this realization of the fundamental role that health plays in the growth process, the literature on economic growth has been slow to fully integrate health within its theories.

Therefore, in this chapter we introduce a brief summary of the evolution of economic growth theories, and a review of the theoretical literature on the relationship between economic growth and human capital. Also, we demonstrate some examples of the different analytical approaches and assessment methods that have been used in dealing with health issues in economic growth models, in both the neoclassical theory of exogenous growth and its extensions, and endogenous growth theories, along with the strengths and limitations of each of these approaches. Finally, we review some results of the empirical work outlining the links between health and economic growth. This chapter forms the theoretical foundation of the following two empirical studies.

2. The Evolution of Macroeconomic Growth Theories

In the 1960s of the past century, economic growth theory has been dominated by the neoclassical model as introduced by Ramsey (1928), Solow (1956), Swan (1956), Cass (1965), and Koopmans (1965). Particularly, the exogenous growth model of Solow (1956) and Swan (1956) has been a cornerstone for the development of subsequent growth models. In the basic setting of the Solow-Swan model, the steady-state output per worker depends on the propensity to save, the growth rate of population, and the position of the production function. The principal assumptions underlying this model are: (1) The production function is of the Cobb-Douglas type, and is homogeneous of degree one, (2) Capital and labour are the factors of production, and they exhibit diminishing returns, (3) Households save a constant fraction of their income and this constant proportion of output is used for capital accumulation, thus the production side determines the level of output when firms maximize their profit.

One of the central arguments of this model, which has been subject to much debate as an empirical hypothesis, is the *convergence* hypothesis or the *catch-up* effect, which stems from the assumption of diminishing returns to capital. According to this hypothesis, economies which have less capital per worker relative to their steady-state level of capital per worker tend to have higher rates of return, and thus they have higher growth rates. So, the growth rate of an economy is predicted to be higher when the starting level of per capita income is lower. As a result, all the economies should eventually converge in terms of their per capita income. Assuming that the only difference between all economies is their starting level of capital intensity, then convergence in the basic model applies in an absolute sense. However, a great body of empirical work shows that convergence applies only in a conditional sense, as economies vary in many aspects such as the propensity to save, willingness to work and having children, access to technology, and government policies (Barro, 1996).

The persistent increase in the growth gap between rich and poor economies, in addition to the basic neoclassical model's incapability of introducing a sufficient explanation for this dynamic, have motivated economists to search for new explanations of long-term growth. As a result, a new wave of theories known as *"The Theories of Endogenous Growth"* has emerged. These are based on the idea that technological progress is endogenous to the growth process, and that it is not the only driving force behind economic growth in the long-term, as many other variables contribute significantly to economic growth, such as the quality of human capital, innovation and knowledge.

The AK model is an early example of endogenous growth theories, and is considered to be the simplest version of them, where output per capita appears as a function of capital and technology. The basic AK model has been introduced by Frankel (1962), who constructed his model based upon both the Solow-Swan and Harrod-Domar models. In this model, capital refers to both physical and human capital, and the level of technology is assumed to be positive and constant. The main feature of this model is the absence of diminishing returns to the factors of production, and therefore capital accumulation can act as the engine for sustained economic growth (Acemoglu, 2009). One of the major criticisms of this model was that it did not explicitly distinguish between capital accumulation and technological progress (Aghion and Howitt, 2008).

Learning externalities is the key factor behind sustainable economic growth in the models of Arrow (1962) and Sheshinski (1967), who described a mechanism in which personal ideas, inventions and discoveries immediately spilled over to the entire economy, where this phenomenon is recognized as "*learning-by-doing"*. Romer (1986), Lucas (1988), and Rebelo (1991) initiated a new wave of endogenous growth theories, built upon the work of Arrow (1962), Sheshinski (1967), and Uzawa (1965). In their works, human capital, in the forms of education, experience, and health, appears as one of the most important determinants of economic growth (Barro, 2013). They emphasized that the spill over of knowledge or information across the economy, and the external benefits gained from human capital accumulation, help in avoiding the tendency for diminishing returns to capital. Therefore, sustained growth can be achieved because the returns to investment in capital accumulation, which includes human capital, are not definitely diminished with the development of the economy.

The inability to predict conditional convergence was one of the weaknesses of the early versions of endogenous growth models. Many efforts have been made in order to extend these models such as to restore the convergence property. The models of technological diffusion are an example of these extensions. In this framework, convergence would apply in a conditional sense as innovations and discoveries related to the rate of technological progress are produced in advanced economies, and then are copied or adopted by follower countries, because imitation tends to be cheaper than innovation. Therefore, these models explain the long-run growth from the point of view of endogenous growth theories as a result of technological progress in developed countries, while interpreting the convergence hypothesis of the neoclassical growth model as a result of the imitation behaviour by follower countries. In these models, a large endowment of human capital is a key factor in the growth process, as it can facilitate the creation, implementation and adaptation of foreign technologies (Benhabib and Spiegel,1994). One major shortcoming of these models was their failure to sufficiently explain why some countries, in a globalized world, have failed in importing and using technologies (Acemoglu, 2009).

Romer (1990), Grossman and Helpman (1990), and Aghion and Howitt (1992) used the Schumpeterian framework of monopolistic competition (Schumpeter, 1934) in order to explain long-term economic growth. In these models, economic growth is driven by technological advances resulting from the private sector's research and development (R&D) efforts that are posteriorly rewarded by some monopoly profits. The technological progress then is ensured by competition between firms, and the creation and implementation of new products, methods of production, and technological innovations. The rate of technological innovation in these models depends significantly on the quality of human capital embodied in scientific research. Also, governmental policies such as taxation, protection of patent and intellectual property rights, and regulation of the other aspects of economy, can affect the private sector's incentives for carrying out research, and thus they play a significant role in achieving long-term economic growth in these models.

In 1992, Mankiw, Romer and Weil extended the Solow-Swan model by adding human capital as one of the main contributors to economic growth (Mankiw et al., 1992). In this extended model, subsequently known as the "*Augmented Solow model*" or the "*MRW model*", human capital, in terms of education, is introduced as a third factor of production. Adding education, in the form of schooling, directly as a contributor to production implies that a country's output growth rate depends greatly on the quality of the stock of human capital or the supply of effective labour force[15]. Knowles and Owen (1995) introduced some further extension to the MRW model by considering health as a capital productive asset and therefore an input in economic growth, thus they explicitly included health as another dimension of human capital in the production function. They argued that the growth in per-capita income is more correlated to health than with education as in the MRW model.

To sum up, the role of human capital in economic growth theories was, for the most part, linked to education until the mid-1990s of the past century, where only a few studies have acknowledged the value of other aspects of human capital, such as health. Over the last few decades, a wide variety of theoretical work has highlighted the role of health as one of the most important factors in the growth process. The positive impact of health on economic growth has been recognized in both exogenous and endogenous growth models. The main difference between the neoclassical theory of exogenous growth and its extensions on one side, and endogenous growth theories on the other side, is that the latter consider technological progress itself to be an economic process. In both types of theories, health status is considered to be one of the main determinants of the supply of an effective labour force, as it influences the accumulation of human capital by improving learning and working capacities. The remarkable theoretical and empirical contributions of Fogel (1994), Barro and Sala-i-Martin (1995), Knowles and Owen (1995), and Barro (1996) have called attention to the importance of the link between health and economic growth in economic debates, and have stimulated further investigations.

3. Modelling Growth to Include Health Capital

The discussion from the previous section shows that many different theories of economic growth have tried to answer the question about the way health conditions can affect countries' economic growth on the long-term. The neoclassical growth theory implies that improvements in health conditions will affect only the level of per capita output in the long-term, but not the growth rate which depends on the global rate of technological progress. The first generation of endogenous growth theories, predicts a permanent impact of health on the growth rate by allowing the rate of technological progress to vary among countries,

[15] The supply of effective labour force refers to the supply of highly skilled or educated workers in an economy. Health and education are considered the main determinants of effectiveness.

depending on local economic conditions. The new endogenous growth theorists also assumed that technological progress is endogenous and variable among countries, but unlike the first-generation models they considered the process of international technology transfer, which makes the rate of technological progress in each country dependent on global as well as local conditions.

The next section introduces in detail some of the main attempts to broaden the concept of human capital, and to extend growth models to include health as one of the major contributors to economic growth. The first model is an extended version of the MRW[16] model as proposed by Knowles and Owen (1995), while the second is an endogenous growth model[17] developed by Howitt (2005) based on the Schumpeterian perspective. In the third model Weil (2007) constructed a macroeconomic framework for estimating the impact of health on per capita income, based on a microeconomic approach for estimating the effect of health on individual outcomes. Finally, the fourth model is a simple theoretical framework proposed by Aghion et al (2011) based on the works of both Lucas (1988) and Nelson-Phelps (1966).

3.1 Health in the MRW model

Mankiw et al (1992) augmented the Solow (1956) growth model by including human capital accumulation, for which they used school enrolment as a proxy. The main conclusion of their cross-section analysis was that the inclusion of the human capital variable as a factor of production, leads to a better fit of the model and a more realistic estimates of the parameters, and removes several anomalous characteristics of the original Solow model. According to Knowles and Owen (1995), a growth model cannot be fully specified without including all main inputs and all drivers of productivity, including measures of all forms of human capital, into the production process, which means that human capital measures should reflect the levels of education and skill, as well as health, as neglecting these aspects could result in a misinterpretation of the determinants of economic growth, and it would then be difficult to know whether a specific variable affects growth directly, or that it is just a proxy for omitted factors. Accordingly, they considered the effect of explicitly including a proxy for health as another dimension of human capital and stated that per-capita income growth had a more robust relation with health than with the education variable of the MRW model. Following Knowles and Owen (1995) the extended MRW aggregate Cobb-Douglas production function takes the form:

[16] This model has a touch of endogenous growth, in the sense that the accumulation of human capital is an endogenous decision, the model would become a full endogenous model with $\alpha + \beta + \gamma = 1$.

[17] It is worth mentioning that there have been several attempts to extend both the first-generation endogenous growth models, like the AK model, and later generations of models, in order to include a health input. For example, van Zon and Muysken (2005) extended an endogenous growth model of the Lucas type to include demographic and epidemiological conditions.

$$Y_{it} = K_{it}^{\alpha} E_{it}^{\beta} H_{it}^{\gamma} (A_{it} L_{it})^{1-\alpha-\beta-\gamma} \qquad (3.1.1)$$

where *Y* is real output, *K* is the stock of physical capital, *E* is the stock of educational capital, *H* is the stock of health capital, *L* is the labour input, and *A* is the labour-augmenting level of technology. The parameters α, β and γ are the elasticities of output with respect to the various types of capital. The subscripts (*i*) and (*t*) denote country and time period respectively. Equation (3.1.1) can be expressed in intensive form as:

$$y_{it} = k_{it}^{\alpha} e_{it}^{\beta} h_{it}^{\gamma} \qquad (3.1.2)$$

Where the quantities per unit of effective labour are $y_{it} = Y_{it}/A_{it}L_{it}$, $k_{it} = K_{it}/A_{it}L_{it}$, $e_{it} = E_{it}/A_{it}L_{it}$and $h_{it} = H_{it}/A_{it}L_{it}$. Assuming that the labour force grows at an exogenous constant rate n_i, and that the technology advance also grows at an exogenous constant rate g, then $L_{it} = L_{i0}exp(n_i t)$ and $A_{it} = A_t = A_0 exp(gt)$. Now if the physical, education and human capital stocks all depreciate at the same constant rate, δ, and if education and health capital accumulation are considered to be an investment activity, where total saving equals total investment, $S = I$, and also assuming that savings are divided among the three types of capital accumulation, then the accumulation of physical, educational, and health capitals per unit of labour can be written as:

$$\dot{k}_{it} = s_{ki} y_{it} - (n_{it} + g_t + \delta_t) k_{it} \qquad (3.1.3)$$

$$\dot{e}_{it} = s_{ei} y_{it} - (n_{it} + g_t + \delta_t) e_{it} \qquad (3.1.4)$$

$$\dot{h}_{it} = s_{hi} y_{it} - (n_{it} + g_t + \delta_t) h_{it} \qquad (3.1.5)$$

wheres_{ki}, s_{ei} and s_{hi} are the fractions of income in country *i* invested in physical, educational and health capitals, respectively. Assuming that a steady state (with $\alpha + \beta + \gamma < 1$) exists, then the steady state values of physical, education and health capitals are:

$$k_i^* = \left(\frac{(s_{ki})^{1-\beta-\gamma} (s_{ei})^{\beta} (s_{hi})^{\gamma}}{n_i + g + \delta} \right)^{1/\eta} \qquad (3.1.6)$$

$$e_i^* = \left(\frac{(s_{ki})^{\alpha} (s_{ei})^{1-\alpha-\gamma} (s_{hi})^{\gamma}}{n_i + g + \delta} \right)^{1/\eta} \qquad (3.1.7)$$

$$h_i^* = \left(\frac{(s_{ki})^{\alpha}(s_{ei})^{\beta}(s_{hi})^{1-\alpha-\beta}}{n_i + g + \delta}\right)^{1/\eta} \quad (3.1.8)$$

where $\eta \equiv 1 - \alpha - \beta - \gamma$. Substituting (3.1.6) to (3.1.8) in (3.1.2), and taking the natural logs gives the extended version of MRW's as proposed by Knowles and Owen (1995). The augmented steady state output per capita is expressed by the next formula:

$$\ln\left(\frac{Y_{it}}{L_{it}}\right) = \ln A_0 + gt - \frac{1-\eta}{\eta}\ln(n_i + g + \delta)_t + \frac{\alpha}{\eta}\ln(s_{ki}) + \frac{\beta}{\eta}\ln(s_{ei}) + \frac{\gamma}{\eta}\ln(s_{hi}) \quad (3.1.9)$$

Equation (3.1.9) indicates a direct relation between the steady state per capita income and physical capital, education and health investment rates, and an inverse relation between per capita income and population growth. It is possible to derive an alternative formulation of this estimating equation according to whether the augmenting capital terms are recorded as rates of accumulation (Mankiw et al., 1992; Knowles and Owen, 1995), as in equation (3.1.9), or as levels. Solving (3.1.7) and (3.1.8) for s_{ei} and s_{hi} in terms of e^* and h^*, and substituting these into (3.1.9) yields income per capita as a function of the steady-state levels of educational and health capital, as follows:

$$\ln\left(\frac{Y_{it}}{L_{it}}\right) = \ln A_0 + gt + \frac{\alpha}{1-\alpha}(\ln(s_{ki}) - \ln(n_i + g + \delta)_t) + \frac{\beta}{1-\alpha}\ln(e_i^*) + \frac{\gamma}{1-\alpha}\ln(h_i^*) \quad (3.1.10)$$

Expressing income per capita as a function of the steady-state level of health capital, can be done by solving (3.1.8) for s_{hi} and substituting in (3.1.9), thus yielding:

$$\ln\left(\frac{Y_{it}}{L_{it}}\right) = \ln A_0 + gt - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n_i + g + \delta)_t + \frac{\alpha}{1-\alpha-\beta}\ln(s_{ki}) + \frac{\beta}{1-\alpha-\beta}\ln(s_{ei}) + \frac{\gamma}{1-\alpha-\beta}\ln(h_i^*) \quad (3.1.11)$$

This equation indicates that per capita income (or output per effective labour unit), is explicitly determined by population (or labour) growth, saving (or investment) rate, and the stock of human capital, as represented by educational level, and health conditions. While equation (3.1.9) is implicitly derived from a steady state expression in terms of levels, the derivation of both equations (3.1.10) and (3.1.11) does require the presumption of a steady state, which according to Mankiw et al (1992) is restrictive and largely determined by data availability. Consequently, when empirically estimating the growth equation, the choice between (3.1.9), (3.1.10), and (3.1.11) depends on human capital data availability, and whether it corresponds more closely to the level of human capital or to its rate of accumulation, taking into consideration that each equation implies different restrictions on the coefficients and different interpretations.

3.1.1 The Convergence Hypothesis

Within the Solow model and its derivates, convergence is quantified through approximating the transition path around the expected final steady state (Mankiw et al., 1992; Islam, 1995). If *y(t)* is the value of income per effective labour at time t, and if y* is its steady state level, then the rate of convergence is given by:

$$\frac{d \ln y(t)}{dt} = \lambda(\ln y^{*} - \ln y(t)) \qquad (3.1.12)$$

where, $\lambda = (n + g + \delta)(1 - \alpha - \beta - \gamma)$ refers to the speed of convergence parameter. This equation implies that:

$$\ln y(t_1) = \left(1 - exp^{-\lambda t}\right) \ln y^{*} + exp^{-\lambda t} \ln y(t_0) \qquad (3.1.13)$$

where$y(t_0)$ is the effective per capita income at the initial period, and $t = (t_1 - t_0)$ indicates the time period under investigation. Subtracting $\ln y(t_0)$from both sides of the previous equation gives the convergence equation, which can be written as follows:

$$\ln y(t_1) - \ln y(t_0) = \left(1 - exp^{-\lambda t}\right) \ln y^{*} - \left(1 - exp^{-\lambda t}\right) \ln y(t_0) \qquad (3.1.14)$$

or after rearrangement:

$$\ln y(t_1) - \ln y(t_0) = \left(1 - exp^{-\lambda t}\right) (\ln y^{*} - \ln y(t_0)) \qquad (3.1.15)$$

The previous equation shows that the greater is the distance from the steady state level of income, the faster is the growth of a specific country. Substituting for y*, growth equations corresponding to the levels equations in (3.1.10) and (3.1.11) can be written as:

$$\ln y_{it} - \ln y_{i0} = \theta \ln A_0 + gt + \frac{\theta\alpha}{1-\alpha}[\ln(s_{ki}) - \ln(n_i + g + \delta)_t] + \frac{\theta\beta}{1-\alpha}\ln(e_i^*) + \frac{\theta\gamma}{1-\alpha}\ln(h_i^*) - \theta \ln y_{i0} \quad (3.1.16)$$

$$\ln y_{it} - \ln y_{i0} = \theta \ln A_0 + gt + \frac{\theta\alpha}{1-\alpha-\beta}\ln(s_{ki}) + \frac{\theta\beta}{1-\alpha-\beta}\ln(s_{ei}) - \frac{\theta(\alpha+\beta)}{1-\alpha-\beta}\ln(n_i + g + \delta)_t + \frac{\theta\gamma}{1-\alpha-\beta}\ln(h_i^*) - \theta \ln y_{i0} \quad (3.1.17)$$

where θ = (1- $\exp^{\lambda t}$). These equations show that health conditions are likely to play a strong causal role in the growth process.

3.2. Health in a Schumpeterian growth model

The main purpose of endogenous growth theory is to gain some understanding of the interaction between technological progress and various structural characteristics of the economy, and how this interaction affects the long-term growth. According to this theory, the rate of technological progress in one country depends not only on its local level of technology, but also on technology spill overs resulting from innovations in other countries, thus it depends on the technology transfer or the international diffusion of technology. Over the past few years, theoretical advances have been made to endogenous growth models in order to include health as one of the main human capital inputs. Howitt (2005) suggested a theoretical endogenous economic growth model that emphasizes the various channels through which health can impact a country's long-term growth. This model extends the neoclassical Solow-Swan model of growth to include the accumulation of human skills. He assumed that the specification of a country's reduced-form aggregate production function, which exhibits constant returns to scale, takes the form:

$$Y = \psi F\big(K, AS(1-\varepsilon)\big) \quad (3.2.1)$$

where *Y* is the total output, *K* and *S* stand for the capital and the skills stocks, respectively, and *A* indicates the aggregate productivity. The parameters ψ and ε represent the productive efficiency and school attendance, respectively. The behaviour of net investment and population growth are described by equations (3.2.2) and (3.2.3) respectively, as follows:

$$\frac{dK}{dt} = \sigma Y - \delta K \quad (3.2.2)$$

$$\frac{dL}{dt} = \eta L \tag{3.2.3}$$

where σ is the saving rate, δ is the depreciation rate, and η is the population (labour) growth rate. The net investment of skills depends on both the gross investment in skills, which is equal to the number of persons enrolled in the learning process multiplied by the learning efficiency parameter, and the skills' depreciation rate that occurs with the death of people acquiring these skills, as is shown by Equation (3.2.4) below:

$$\frac{dS}{dt} = \lambda \varepsilon L - \phi S \tag{3.2.4}$$

where λ represents the learning efficiency parameter, $\varepsilon(\varepsilon < 1/2)$ refers to school attendance, and ϕ is the skill-adjusted death rate. Howitt (2005) indicated that these first four equations represent an extension of the neoclassical model which takes into account the accumulation of skills. Along with these, an additional set of four equations is used to endogenized the rate of technological progress. First, under the assumption that the country spends a fixed fraction ρ of its total output on technology investment *R*, then we may write:

$$R = \rho Y \tag{3.2.5}$$

where ρ refers to country's research intensity ($\rho<1$). Second, the technological progress in the country is assumed to depend on both its domestic rate of innovation *v*, and its distance from the global technology frontier (A^*-A), as indicated by Equation (3.2.6) below:

$$\frac{dA}{dt} = v(A^* - A) \tag{3.2.6}$$

Third, under the assumption that the country's technology frontier grows at a given rate g^*, then:

$$\frac{dA^*}{dt} = g^* A^* \tag{3.2.7}$$

The previous two equations (3.2.6) and (3.2.7) indicate that if the country's domestic innovation rate *v* is constant, then its productivity will grow at the same rate as the global technology frontier, consequently its economic growth rate would converge in the long run to the global growth rate g^*. The fourth and last equation is used to indicate that the innovation rate *v* has a positive relationship with technology investments, while it is inversely proportional to population (labour) size, thus:

$$v = \frac{\mu R}{A^{*}L} \quad (3.2.8)$$

where μ refers to the research efficiency. According to this specification, the assumption that more populous countries tend to grow faster as a result of the population scale effect is invalid.

Howitt (2005) emphasized that this model can help in identifying the main channels through which the improvements in health can impact economic growth. First, equation (3.2.1) captures the impact of health improvements on productive efficiency, in terms of the value of the parameter ψ. Second, equation (3.2.4) indicates that an increase in life expectancy due to health improvements has a direct effect on population average skill level, through the impact on the skill-adjusted death rate ϕ. At the same time, the increase in life expectancy and better health conditions may have positive effects on the saving rate σ, and can play an important role in educational achievements, represented by the parameters λ and ε, which refer to learning efficiency and school attendance, respectively.

According to this model, an improvement in population health status is expected to have a positive effect on the parameter μ in equation (3.2.8), which refers to research-efficiency, and may also increase the value of the parameter ρ indicating research-intensity, in equation (3.2.5). Howitt (2005) pointed out that the final channel through which health improvements can impact the long-term economic growth is reducing income inequality, which in turn has significant positive impact on school attendance.

Howitt (2005) indicated that the previous eight equations model can be simplified to become a simple two-dimensional dynamical system, by taking into account that both the population growth equation (3.2.3) and the skills investment equation (3.2.4), imply that in the long-term the stock of skills per unit of effective labour, given by $s \equiv S(1-\varepsilon)/L$, will converge to:

$$s = \frac{\lambda\varepsilon(1-\varepsilon)}{\phi+\eta} \quad (3.2.9)$$

In addition, the law of motion governing the evolution of the capital stock per unit effective labour, $k \equiv K/AL$, can be described as:

$$\frac{dk}{dt} = \sigma\psi F(k,s) - (\delta+\eta+g)k \quad (3.2.10)$$

Equation (3.2.10) represents the fundamental differential equation of the Solow-Swan model, where $g \equiv (dA/dt)/A$ is the technological progress rate. Howitt (2005) assumed that if a country's relative productivity is given by $a \equiv A/A^*$, then in the long run, the proportional income gap between this country and the world's technology leaders will be proportional to a. Given equation (3.2.7) and this definition for a, then:

$$\frac{da}{dt} = a(g - g^*) \tag{3.2.11}$$

and from equations (3.2.1), (3.2.5), (3.2.6) and (3.2.8) we can get:

$$g = \mu\rho\psi F(k, s)(1 - a) \tag{3.2.12}$$

A system of two differential equations in the two dynamic variables k, the capital stock per unit effective labour, and a, the country's relative productivity, can be obtained by substituting (3.2.12) into (3.2.10) and (3.2.11). In general, the model by Howitt (2005) illustrates the different channels through which health improvements can impact long-term economic growth, and emphasizes the role of spill over effects, i.e., that higher levels of human capital in the form of education and health can have a significant impact on the innovation rate and, consequently, on the growth rate of productivity.

3.3. Health in a Macroeconomic framework based on Microeconomic Estimates

Weil (2007) started his analysis with assuming that the aggregate production function that depends on capital and a composite labour input, takes the next Cobb-Douglas form:

$$Y_i = AK_i^{\alpha}(H_i)^{1-\alpha} \tag{3.3.1}$$

where Y is total output, K is physical capital, H refers to the composite labour input, A stands for productivity, and i denotes countries. He assumed that H_i, is determined as follows:

$$H_i = h_i v_i L_i \tag{3.3.2}$$

where h_i is human capital per worker in terms of education, v_i is human capital per worker in terms of health, where health here refers to the aspects of worker health that are related to the production process, and L_i stands for the number of workers. According to this specification, a more educated and healthier worker tends to produce more units compared to workers who are less educated or healthy. Weil (2007) pointed out that this assumption is difficult to justify in the case of education, as one well educated worker cannot be a perfect substitute for a number of illiterate workers. But the case of health is different, and the assumption may apply, as one healthy worker who can work faster or longer can be a substitute for several unhealthy workers. Assuming that the unit of composite labour is paid a wage w_i, equal to its marginal product, then:

$$w_i = \frac{dY_i}{dH_i} = (1-\alpha)A_i\left(\frac{K_i}{H_i}\right)^{\alpha} \quad (3.3.3)$$

Assuming that the income (wage) earned by worker *j* depends on his own level of health and education, in addition to the domestic wage level of composite labour, i.e. the personal wage is proportional to the worker's level of human capital in terms of health, then we may write that individual wage, in log form, as:

$$\ln w_{i,j} = \ln w_i + \ln h_{i,j} + \ln v_{i,j} + \eta_{i,j} \quad (3.3.4)$$

where $\eta_{i,j}$ is an individual-specific error term.

Weil (2007) assumed that individual health outcomes are a function of health inputs, in addition to a set of random errors. He introduced the determinants of two health outcomes. The first is *I*, which refers to observable elements of health outcomes, while the second is *v*, which has been defined before as the health outcome that is relevant for labour productivity. These are estimated as:

$$I_j = a_1 + \gamma_I z_j + \epsilon_{I,j} \quad (3.3.5)$$

$$\ln v_j = a_2 + \gamma_v z_j + \epsilon_{v,j} \quad (3.3.6)$$

In these equations, *z* represents a measure of health status, *I* is an indicator of observable health outcomes, and a_1 and a_2 are constants. According to Weil (2007), the relationship between the vector of health inputs *X*, and health outcomes, such as *I* and *v*, is mediated through changes in health conditions, so he assumed the effect of *z* on health outcomes to be linear in the case of *I*, and log-linear in the case of *v*.

For two individuals of health status z_i there would be a wage gap. Assuming that human capital in the form of schooling is constant, the expected gap in log wages becomes:

$$\ln w_2 - \ln w_1 = \gamma_v (z_2 - z_1) \quad (3.3.7)$$

and the expected difference in the health outcomes indicator *I*, is:

$$I_2 - I_1 = \gamma_I (z_2 - z_1) \quad (3.3.8)$$

Combining (3.3.7) and (3.3.8) shows that the expected ratio of the log wage gap to the gap in health outcomes indicator *I* is:

$$\ln w_2 - \ln w_1 = \frac{\gamma_v}{\gamma_I}(I_2 - I_1) \quad (3.3.9)$$

where the ratio γ_v/γ_I refers to the economic return to health outcome indicator *I*, noticing that health outcomes are just an indicator of underlying health. Weil (2007) indicated that the differences among countries in human capital per worker in the form of health, which is unobservable, can be obtained by using observable health indicators for a pair of countries as follows:

$$\ln v_2 - \ln v_1 = \rho_I(I_2 - I_1) \quad (3.3.10)$$

where ρ_I refers to the return on health outcome indicator *I*, which can be estimated as a ratio, as follows:

$$\rho_I = \frac{\gamma_v}{\gamma_I} = \frac{\ln v_{t+1} - \ln v_t}{I_{t+1} - I_t} \quad (3.3.11)$$

Weil (2007) emphasized that because of the difficulties associated with the direct observation of average *v* for countries, it is better to depend on an individual-level data approach to estimate the return to health outcomes, which can be applied by using an experimental or quasi-experimental variation in the vector of health inputs, *X*. Assuming that *x* is some health input, such that $x \in X$, and the variation of *x* is exogenous, then its impact on both health outcomes (d_I/d_x) and wages (d_w/dx) can be estimated without bias. According to equations (3.3.5) and (3.3.6), $dw/dx = (dz/dx)\,\gamma_v$, and $dI/dx = (dz/dx)\,\gamma_I$, thus:

$$\rho_I = \frac{\gamma_v}{\gamma_I} = \frac{dw/dx}{dI/dx} \quad (3.3.12)$$

Equation (3.3.12) says that the return to a health outcome depends on the relationship between the impact of varying health input on wages and the effect of varying health input on that health outcome. In this model Equation (3.3.10), is considered to be the fundamental equation, and is the basis of cross-country analysis of economic growth differences which depend on the degree to which human capital in the form of health (the aspect of health which is related to production process) varies across countries.

3.4. Health in a Lucas and Nelson-Phelps Model

Aghion et al (2011) argued that combining the Lucas (1988) and Nelson-Phelps (1966) perspectives of human capital helps in gaining a better understanding of the relationship between health and economic growth. They proposed a simple model where both the accumulation and the level of health are important contributors to growth. They assumed that the final output is produced with one factor, which is human capital represented in terms of health, so that per capita output in any period is given by:

$$Y = AH^{\beta} \tag{3.4.1}$$

where $0 < \beta < 1$, H refers to the current stock of human capital, and the parameter A stands for labour productivity. Equation (3.4.1) says that labour become more productive when they have higher level of health, which means that a higher level of health increases the amount of labour efficiency in the economy as a whole. Taking natural logs, the production function becomes:

$$y = a + \beta h \tag{3.4.2}$$

where the lower-case letters denote natural logs. Aghion et al (2011) demonstrated that equation (3.4.2) includes the Lucas effect of human capital, which states that health accumulation, $\dot{h}$, should have a positive effect on the growth of output, $\dot{y}$. They assumed that labour productivity evolves over time according to the Nelson-Phelps equation, then:

$$\dot{a} = \theta(\bar{a} - a) + \alpha h + \delta \tag{3.4.3}$$

where $\bar{a}$ represents the log of the current global productivity frontier, and where θ, α, δ, are all constants. This specification means that the higher the stock of health capital, the higher is the level of population intellectual ability. Accordingly, it is easier for the current labour productivity a to catch up with the current global productivity frontier or with what they called the "current world best practice" $\bar{a}$.

Combining (3.4.2) and (3.4.3), shows that the growth of per capita output, depends on both the level and the accumulation rate of health capital, according to:

$$g = \dot{y} = \theta(\bar{a} - a) + \alpha h + \beta \dot{h} + \delta \tag{3.4.4}$$

Otherwise, this growth equation can be expressed as:

$$g = \delta + \theta\bar{a} - \theta y + (\alpha + \beta\theta)h + \beta\dot{h} \quad (3.4.5)$$

This equation shows that the growth of per capita output depends negatively on the country's initial level of output, positively on both the level and accumulation rate of health, and positively on current world productivity. According to Aghion et al (2011), when $\theta = 0$, the growth cannot depend on all three variables (a,h,$\dot{h}$) or (y,h,$\dot{h}$), but only on two of them.

3.5. Economic Growth Models: Merits and Limitations

Following this review, it can be said that economic growth theory has incorporated health as a component of human capital for gaining a better understanding of the economic growth process and its determinants and mechanisms. The main scope of this review was to explain how the main theoretical approaches, the neoclassical Solow-Swan approach and the endogenous growth approach, have adapted to the evolution of the concept of human capital by introducing some of the theoretical methodologies, and a glimpse of the alternative modeling specifications that have been most frequently used in literature. While the relative merits of each approach can be, and have been, endlessly debated, it is clear that both approaches have their own strengths, and also their own limitations which have to be considered, especially when choosing an empirical design.

The main criticism of the neoclassical theory is the assumption that the economy grows exogenously in the long-run. Francesco Caselli, Gregory Mankiw and David Romer, in their comments on the work of Bernanke and Gurkaynak (2001) emphasized that this argument turns a model's useful simplifying assumption into the model's main insight. David Romer stated that "*No one believes that growth is exogenous: growth, like everything else, has a cause. The assumption of exogenous long-run growth is a useful modelling device, not a serious hypothesis*". Many authors emphasized that when the neoclassical growth theory is appropriately refined, it can explain the pattern of economic development satisfactorily, and that the inclusion of human capital input is quite useful for understanding the evolution of income distribution around the world, as this model can explain a significant portion of the observed cross-country income levels variations (Barro, 1996; McCallum, 1996; Bernanke and Gurkaynak, 2001; Parente, 2001) On the other hand, McCallum (1996) argued that explaining levels is not that important and cannot be accepted as the main task of a theory of economic growth.

Barro (1996), Fine (2000) and Parente (2001) pointed out that endogenous growth theories, especially theories of basic technological change, enhance the understanding of the growth in world knowledge over time, and can sufficiently explain long-term growth, and why the world as a whole can continue to grow indefinitely in per capita terms. However, these theories have had a limited ability in explaining the determinants of relative growth rates across countries, which are considered to be the key element and the focus in empirical work on growth. Many other authors show strong views against the merits of endogenous models. Mankiw et al (1992) argued that the endogenous models have much less explanatory power of the observed facts than the Solow model. Jones (1995) indicted that the conclusions of the endogenous models cannot be supported by the observed time series facts. It is worth noting that the vast majority of empirical work on growth has received more insights from the neoclassical model, as extended to include human capital, governmental policies, and technology diffusion.

Parente (2001) mentioned that several of endogenous growth models such as R&D models, can be looked upon as models of technology adoption, that are based on the interesting idea of the accumulation of intangible capital. However, these models failed to consider many key development facts, especially when adapted to the developing countries. He argued that the failure of R&D models in answering simple questions like why don't all poor countries, that do not engage in R&D, adopt the more productive available technologies that have been developed elsewhere in the world, in order to increase their per capita output in a costless way?. These failures led him to the conclusion that endogenous growth theory is not a reliable theory of economic development.

The endogenous growth literature tried to provide an interpretation for the differences in growth rate across countries based on ongoing, steady-state growth in per capita output values. McCallum (1996) indicated that the ability of these models to obtain a steady-state growth seems very small, as this result requires a highly special (zero measure) parameter values. Furthermore, the complex nonlinear structure of the parameters in endogenous growth models is hard to be estimated with country specific time series data. The empirical work on cross section and panel data, usually depend on *ad hoc* reduced form growth equations, such as to avoid estimating structural parameters. Cesaratto (2009) indicated that the estimation of these *ad hoc* growth equations is usually done by using explanatory variables that are arbitrarily selected. Consequently, the empirical tests do not provide unequivocal results, and the conclusions obtained from different studies strongly depend upon the selected explanatory variables, and the chosen analytical functions and the values attributed to the parameters.

The difficulties of estimating structural theoretical endogenous models, and the use of arbitrary specifications, have been of the main criticisms of these models. The model selection issue involves many complications, as different studies use different proxies for the variables even when applying the same growth theory. Moreover, the main problem with the aforementioned *ad hoc* growth equations, is that in much of the empirical work it is not clear whether these specifications are based on, or derived from the theoretical growth models, or the way they have been derived. It is also sometimes not clear whether the estimated relationship is a production function or a growth equation. In addition, the theoretical models usually use one or two growth enhancing variables, thus, any variable that is believed to generate considerable externalities is included in the empirical studies on growth. Durlauf (2005) referred to this and indicated the large number of different growth enhancing variables that have been selected in the empirical models.

Despite the widespread view that the Solow (1956) model does not provide significant policy implications for growth in the long-run, while endogenous growth models with their policy effectiveness over long-run growth, can sustain the growth of per capita income. Yet, both approaches do not account for the difference between policy needs in developing countries and those of the developed ones. As noted by Hicks (1965), advances in growth theory do not have much relevance for the developing economies. The main interest of endogenous growth models is the long run growth effects of policies. In fact, this is not very useful for the vast majority of developing countries, whose main focus is on how to achieve short or medium-term growth, and on how to adopt, or copy, foreign technology and innovations in order to accelerate the technological catch-up. Accordingly, endogenous growth models are of limited utilization for policy makers in developing nations, decision makers are most likely to be motivated to apply these long-term policies once they have accomplished higher levels of income and growth in the short or medium term. On the other hand, the re-examination of cross-country implications of the exogenous growth models, revealing that the neoclassical growth theory can be more useful in analysing and predicting economic growth across developing countries.

To sum up, in dealing with growth theory, economists seem to be split into two camps: those who support endogenous models with their effective growth policies in the long-term, and those who favour the neoclassical model or some of its extended versions, which limit the policy impact over the transition periods. Apart from this, it is difficult to state that one of these models is better than the other. The characteristics of endogenous growth theories, such as the micro-macro bridge, the policy effectiveness and their ability to incorporate the variables that neoclassical models have been criticized for omitting, those relating to shifting productivity, institutions and market imperfections more generally, allow them to generate significant theoretical, policy and empirical conclusions. On the other hand, one of the main reasons of the success of the neoclassical growth model is that it provides a convenient tool for organizing data on the sources of economic growth, although much of the growth was left "unexplained." In general, the policymaking process will benefit more from empirical results generated from more carefully constructed structural economic models.

Referring specifically to health, in this section we demonstrated four different model specifications. The extended version of the MRW model as proposed by Knowles and Owen (1995), or the so called the augmented Solow model, which considers the health dimension as an extra input on the production function and emphasizes its impact on the level of output. Howitt's (2005) model, that takes into consideration the spill over effects that higher levels of human capital in the form of education and health can have on the innovation rate and, consequently, on the growth rate of productivity. Weil's (2007) model, which is calibrated using microeconomic evidence for parameter values. According to this model, the microeconomic estimation measures the impact of improvements in an individual's human capital on his/her own earnings, and ignores the additional effects or the externalities it might have on the society as a whole, by estimating the returns to human capital in aggregate, inferences about the existence and magnitude of the externalities can be obtained. Finally, the fourth model represents a simple theoretical framework proposed by Aghion et al (2011) based on the work of both Lucas and Nelson-Phelps. One of the main problems facing the Lucas specification is that human capital probably cannot be accumulated without bound. In fact, both the descriptions of the approaches by Howitt (2005) and Aghion et al (2011) allow a deeper understanding of how the linkages between human capital and economic performance may work and how they contribute to enhance further economic gains. Nevertheless, a major problem that faces this kind of modelling (and common to other endogenous growth model specifications, as discussed before) is its reduced applicability for empirical analysis, which explains why a great part of empirical analysis follows the MRW approach. Therefore, in the empirical analysis measuring the impact of environmental degradation on economic growth through the health channel, we will follow the MRW approach.

4. Health in Empirical Growth Work

The empirical literature on health and economic growth, from either the macro or micro economic perspectives, includes several attempts at investigating the way various health indicators are linked to economic growth. The main interest of studies at the macroeconomic level, both across countries and within each country, was to quantify the effect of human capital, in terms of health or the joint effect of health and education, on the total economic output. On the other hand, research at the microeconomic level, has mainly focused on analysing the impact of health on wages. A wide variety of health indicators have been employed in these studies in order to detect these heath impacts. Life expectancy at birth, probability of surviving and infant mortality rates, the fertility rate, the prevalence rates of specific diseases, and health expenditures, are the most commonly used indicators in macroeconomic studies. Microeconomic studies construct their assessments based on some anthropometric measures, such as height and weight, along with estimates obtained from household surveys for the prevalence of particular diseases, and the way these impair individuals' physical activities and reduce their earnings. In this section, we survey some of the empirical attempts at examining the channels through which health outcomes can impact economic growth performance.

The human capital model of the demand for health, as developed by Grossman (1972), has been a landmark for modelling the impact of health improvement on economic output. According to Grossman (1972), health is considered to be a capital asset, as people invest in themselves via health, education, and training in order to increase their returns, thus health can be analysed likewise consumption or investment goods. At the same time, higher wages yield higher optimal levels of health stock, as higher earnings are expected to increase the consumption of health-related goods, such as adequate food and medicine (Lopez et al., 2005). Also, Grossman (1972) has pointed out that the economic cost of poor health manifests in the lost labour time due to sickness that prevents or impairs work. Based on the work of both Becker (1965), Grossman (1972), and Strauss and Thomas (1998) have developed a household production model in order to test the effects of health on economic development, via its impact on wages and earnings, labour supply, and time allocation. Their findings indicated the existence of a causal impact of health on both wages and productivity. As a considerable body of microeconomic evidence has documented the various channels through which health affects economic outcomes, many efforts have been paid in order to test whether such effects can be translated into an aggregate impact of population health on economic growth (Bloom, et al., 2018).

With the aim of exploring the relationship between health and economic growth at the aggregate level, the empirical work of Knowles and Owen (1997) has focused on the impact of health on economic growth through the labour productivity channel, where health improvements raise workers' ability to produce more units, and thus increase per capita income directly. The authors have extended the neoclassical framework to include both education and health. They estimated a structural growth equation, where education and health have been included in the aggregate production function as labour-augmenting variables. Their findings from cross-country analysis indicated the existence of a strong positive impact of health, in terms of life expectancy, on economic growth, and that an improved health status has productivity-enhancing effects. On the contrary, they found the relationship between education and output per worker to be insignificant.

Built upon the microeconomic evidence of the importance of health and work experience as forms of human capital, Bloom et al (2001) tried to assess the strength of the effect of both factors on labour productivity at the macroeconomic level, and to examine their ability to explain economic growth. Their model includes an aggregate production function where total output is expressed as a function of physical capital and labour inputs, in addition to human capital in terms of education, experience, and health where these factors refer to the efficiency with which production inputs are used or the total factor productivity (TFP). They estimated the parameters of the aggregate production function, and then regressed the residual productivity on health measures, using panel data for the period from 1960 to 1990, in order to obtain measures of the relative contributions of each of the inputs and of TFP to economic growth. Their findings indicated that health has a positive and statistically significant effect on economic growth, where an improvement in a population's life expectancy by one year increases output by 4 percentage points. In addition, they emphasized that cross-country differences in life expectancy and average years of schooling, can explain a substantial proportion of the observed income gaps between countries. These findings are akin to those obtained from similar research carried out by Bloom et al (2004).

The indirect effect of health on economic growth has been less investigated in empirical works. Health is found to be one of the main determinants of educational level, while education is among the few variables which are statistically significant for explaining economic growth. Therefore, education is considered to be one of the channels through which health can indirectly affect economic growth. Evidence from many studies, has suggested that economic growth in the long-term depends largely on the stock of human capital, which increases as a result of better health and higher level of education (Lopez et al., 2005). According to Bloom et al (2004), an improvement in health during childhood leads to better school attendance and enhances the learning capacity, thus it has a real effect on labour productivity. At the same time, a lower mortality and an increase in the expectation of life span resulting from health improvements would encourage people to invest more in human capital, which in turn increases capital accumulation, thus increasing the aggregate output. They concluded that health improvements may increase output directly through increasing labour productivity, or indirectly through enhancing the capital accumulation process.

The cross-country study of Lorentzen et al (2008), is an example of attempts to capture both the direct and indirect impact of health, via education, on growth. In that work, the authors employed a system of equations approach, in addition to using adult mortality rates as a proxy for health in order to isolate the impact of adult mortality from that of child mortality. The main weakness of their approach was the exclusion of health in the main growth regression, where it was only included as one of the determinants of educational level in the education equation. As a result, the potential direct and indirect impacts of health on economic growth couldn't be simultaneously captured. Ashraf et al (2008) have developed a simulation model in order to measure quantitatively the effect of health improvements on per capita output. In their model they tried to capture both the direct effect of health on worker productivity, and the indirect impacts that running through schooling, the size and age-structure of the population, capital accumulation, and crowding around fixed natural resources. They proxied changes in general health by improvements in life expectancy and the prevalence of certain diseases, namely malaria and tuberculosis. Their findings suggested a considerably lower effect of health improvement on income per capita, compared with those that have been documented in previous studies and are often considered by policy makers.

One of the most important channels through which health may affect economic growth is population growth which influences labour supply. The impact of better health on population growth is ambiguous, as many empirical studies have demonstrated mixed results. Bloom and Canning (2000) indicated that in the short-term, an increase in child survival rates results in speeding up population growth. Over a longer time span, this reduction in infant and child mortality may subsequently reduce fertility rates, thus causing the net rate of reproduction to fall. Bloom et al. (2009) showed that reductions in fertility accompanied by lower mortality have a positive effect on labour supply.

The impact of health on savings is another channel through which health affects economic growth. Modigliani (1970) pointed out that changes in health in terms of changes in life expectancy, may cause changes in saving rates. According to Modigliani's life-cycle model of savings, an increase in life expectancy in the short term would motivate young workers to save at a relatively high rate, which in turn increases capital accumulation. Meanwhile, an increase in the probability of surviving beyond the age of effective participation in labour force, would increase saving rates in the long run. He emphasized that despite the importance of these mechanisms, a quantitative assessment of life-cycle savings' effects on economic growth in developing economies remains a challenge to empirical work.

Regarding health indicators, Bloom et al (2004) have summarized the results of several empirical works that aimed at investigating the direct impact of health on economic growth using life expectancy at birth as a proxy for health, and which mostly reached similar quantitative results, such as Barro and Lee (1994), Sachs and Warner (1997), Bhargava et al (2001), and Barro and Sala-i- Martin (2004). Across these studies, life expectancy has been found to have a positive and significant effect on economic growth, and to be accepted as a valid proxy for health. For example, the empirical findings of Barro (1996), for a panel of 100 countries, showed that economic growth is positively related and is enhanced by higher initial schooling and life expectancy, and that an increase in life expectancy at birth by about 10 percentage point leads to an increase of almost 0.50 percent in economic growth.

Acemoglu and Johnson (2007) have explored the impact of improvements in life expectancy that have been globally witnessed since the 1940s of the past century on economic performance, where they used data on predicted mortality from various diseases as an instrument. Their findings indicated that predicted mortality has a significant impact on the changes in life expectancy, and that an increase of one percentage point in life expectancy leads to an increase in population by approximately 1.7 to 2 percentage points. They also found that health, in terms of life expectancy, has a much smaller effect on total output, and that there is no evidence for a large increase in income per capita corresponding to increases in life expectancy, in contrary to the studies that found a positive significant impact of health improvements, as indicated by life expectancy at birth, on economic growth (Barro and Lee, 1994; Barro and Sala-i-Martin, 1995; Caselli et al., 1996; Sachs and Warner, 1997; Bloom and Sachs, 1998; Bloom et al., 2001; Bloom et al., 2004), and the great body of empirical work that showed a positive and significant impact running from health to economic growth and vice versa (Barro, 1991 and 1996; Barro and Lee, 1994; Barro and Sala-i-Martin, 1995; Knowles and Owen, 1995 and 1997; Sachs and Warner, 1997; Gallup and Sachs, 2000; Mayer, 2001; Bloom et al., 2001and 2004; Weil, 2007; Aghion et al., 2011).

Bloom et al (2013) criticized the study of Acemoglu and Johnson (2007), on the grounds that their evidence for improvements in population health not stimulating economic growth, relies critically on the baseless assumption that the initial level of health has no causal effect on subsequent economic growth, whereas childhood health has been evident to affect adult productivity in many works. They repeated the study using an augmented model that includes initial health, and their findings indicated that the instrumental variable suggested by Acemoglu and Johnson (2007) has no significant predictive power for improvements in health, thus it does not identify the effect of health improvements on economic growth.

Although health, in the form of life expectancy at birth, has been used in a large body of growth regressions, and has been found to have a significant positive impact on the rate of economic growth, a number of studies have raised concerns about whether life expectancy is a good proxy for health improvement (Bloom and Canning, 2003), as the extension of lifetime may also reflect higher labour force participation, rather than indicating health improvements. The answer for the question of whether health stimulates growth directly or is just a proxy for some other omitted or mis-measured factors is still not clear.

The probability of survival by age and gender groups has been frequently used as an indicator of health status in health-growth empirical work. Mayer (2001) adapted the Granger causality test in order to investigate the relationship between health improvements and economic growth on the long-term. He used data on the adult survival rate (ASR), as an indicator of health improvements for eighteen Latin

American countries, during the period from 1950 to 1990. His findings emphasized a strong evidence of conditional causality from health to income. He also emphasized that a permanent increase in annual income by an amount ranging between 0.8% and 1.5% is associated with typical health improvements for both adult and old age populations. In addition, he pointed out that in order to fully consider the economic effects of health, the various channels of causation from health to income need to be well identified.

An analytical framework used by Weil (2007) has been constructed based on microeconomic estimates in order to obtain a quantitative assessment of the role of health in explaining income gaps across countries, and the economic returns to health improvements, especially for people living in the less developed countries. He used three health indicators as proxies for health status, namely the ASR, average height, and age at menarche. His main finding was that differences in health status can explain a significant part of income variations among countries, and that eliminating these differences would turn down the variance of income by about 9.9 percentage point. He also pointed out that although this impact is economically significant, yet it is essentially small compared to the estimated impact of health on economic growth that is derived from cross-country regressions.

Health care expenditure is another common health indicator. Rivera and Currais (1999a) investigated the relationship between health and economic growth in member countries of the Organization for Economic Co-Operation and Development (OECD), during the period from 1960 to 1990, where they used per capita health care expenditure as an indicator of health. Their findings showed that health is a significant determinant of workers' performance and productivity, that investment in health is an important contributor in output to economic growth, and that countries which spend more on health care tend to have higher economic growth rates. Hashmati (2001) extended the augmented Solow model in order to test the conditional convergence hypothesis in OECD countries. He used health expenditures as a proxy for health status in the growth function. His findings indicated a one way causality running from health care expenditure to GDP. His results also indicated a rate of convergence of 3.7 percent per year of income per capita in OECD countries, to their steady state level. He concluded that health care expenditures have a positive effect on the economic growth and on the speed of convergence. However, in contrary to the MRW model predictions, he found that the impact of the inclusion of human capital in the growth model is insignificant.

Wang (2015) estimated the optimal health care expenditure in the OECD member countries over the period from 1990 to 2009. His findings emphasized that the real level of health spending in OECD countries is about 5.48% of GDP, with an average of 1.87% economic growth rate, He also found that the optimal ratio of health spending to GDP is about 7.55%, and that when the ratio is less than this level, an increase in health care spending will effectively lead to better economic performance. He claimed that measuring the optimal level of health care spending is of great importance in helping policy makers in the resources allocation process, especially in the current context of financially constrained health systems around the world. Piabuo and Tieguhong (2017) examined the impact of health, in terms of government health spending, on economic growth in the member countries of the Economic and Monetary Community of Central Africa (CEMAC). Their findings showed that health care spending has a positive and significant effect on economic growth, where an increase in health expenditure by one unit leads to an increase in GDP per capita by an amount ranging between 0.3 to 0.38 units.

Poor health conditions and the prevalence rates of particular diseases have been frequently used in the context of investigating hindrances to economic growth, especially in developing countries. Acemoglu et al (2003) showed that health conditions and disease environments have a significant impact on economic outcomes. He suggested that the indirect effect of health conditions, via institutions, on the economic development is more important than the direct effect of these factors on income. He pointed out that the direct effect of health on income can explain only a small fraction of the differences in per capita income across countries, while variations in health conditions and disease environments had a remarkable impact on the path of institutional development, and consequently on economic growth, during the period of European colonial expansion. Bloom et al (2014) estimated the economic impact of the five main NCDs, namely cardiovascular diseases, cancer, chronic respiratory diseases, diabetes, and mental disorders, in China and India during the period from 2012 to 2030. They focused on the negative effects of NCDs on both labour supply and capital accumulation. Their findings indicated that these diseases would cost China and India nearly 27.8 and 6.2 trillion USD, respectively. The authors emphasized that for both countries, the most costly diseases are cardiovascular disease and mental disorders, followed by respiratory diseases.

As the literature review above on the relationship between health and economic growth reveals, the vast majority of empirical works have found good health to impact economic growth positively via various channels, such as education, labour productivity and supply, and savings, and that the effects of human capital, in the form of health, on economic growth is found to be sensitive to the datasets used, to model specification, and to the methods used in estimation. The commonly used proxies for health are life expectancy (Barro and Lee, 1994; Barro and Sala-i-Martin, 1995; Caselli et al., 1996; Sachs and Warner, 1997; Bloom and Sachs, 1998; Bloom et al., 2001; Bloom et al., 2004), ASR (Bhargava et al., 2001; Mayer, 2001; Arora, 2001; Bloom and Canning, 2004; Weil, 2007, Bloom et al., 2018), health expenditure (Rivera and Currais, 1999a; Hashmati, 2001;Wang, 2015; Piabuo and Tieguhong, 2017; Sethi et al., 2020; Esen and Çelik Keçili, 2021), mortality from particular diseases, such as malaria (Gallup et al., 1998; Gallup and Sachs, 2000; Sachs, 2003; Carstensen and Gundlach, 2006), HIV/AIDS (Cuddington and Hancock, 1994; Bonnel, 2000), and non-communicable diseases (Bloom et al., 2014).

The literature review also shows that the economic impact of environment-related diseases has not been extensively investigated in empirical works. Therefore, in order to explore the impact of environmental degradation on economic growth, and in order to capture the role that poor health resulting from environmental degradation plays in this regard, we will use disability and mortality due to diseases related to ambient air pollution as a proxy for health in our empirical investigation.

Chapter 2

Air Pollution, Health, and long-Term Economic Growth: an Empirical Investigation

1. Introduction

As mentioned in the previous chapter, the various channels through which health may impact economic growth have been an interest in a growing body of the literature on health and economic growth. Literature review shows that the vast majority of empirical works have found good health to influence the output level of a country via various channels, such as education, savings, and labour productivity and supply. Another economic impact of good health is reducing healthcare expenditures, thus freeing some of the resources used for healthcare towards alternative uses. On the other hand, poor health reduces both the supply of labour, and the ability of labour to work, and hence the productivity of human capital. Health status is vitally influenced by the quality of the air which people breathe. Research over the past few decades have elucidated several mechanisms by which poor air quality impacts health status and quality of life, with these research efforts still ongoing. The WHO emphasized that air pollution is ranked among the top risk factors for death and disability worldwide[18], as breathing polluted air is associated with a broad spectrum of acute and chronic health impacts, and also indicated that approximately 91% of the world's population is exposed to air pollutant concentrations exceeding the recommended levels.

The impact of air pollution on human health may differ depending on the pollutant constituents. PM air pollution has been found to be related to the most serious health impacts, especially chronic pulmonary conditions, mortality from lung cancer, and cardiovascular and respiratory diseases. The estimation of the global burden of PM air pollution in 2015 indicates that it accounted for approximately 5% of mortality from lung cancer, nearly 3% of mortality from cardiovascular diseases, and about 1% of mortality from acute respiratory infections in children under five years of age. This represents about 0.8 million premature deaths and 6.4 million YLLs, where this burden mostly occurred in developing countries.

Therefore, this work explores the way environmental degradation impacts long-term economic growth, emphasizing the link between pollution and health as the main channel of transmission. Our central argument is that an assessment of the link between population health and economic growth on one hand, and the relationship linking health status to environmental quality on the other hand, will help in

[18] The main stated subject of the first WHO Global Conference on Air Pollution and Health in 2018 was "Improving Air Quality, Combating Climate Change: Saving Lives". The conference called for an urgent global response in order to prevent diseases caused by air pollution and indicated air pollution as the greatest environmental health risk, and as a major driver of NCDs, especially heart diseases, stroke, and lung cancer. The conference also emphasized the role played by air pollution as a contributor to accelerating climate change.

achieving a clearer understanding of the trade-offs between these variables. In other words, calling attention to the simultaneous interdependence between environmental degradation, health, and economic growth, can help in answering many crucial questions concerning the way environmental degradation impacts economic growth. For example, if an increase in economic output can be attained by increasing investment in physical and human capital, where in many countries this usually comes at the cost of increasing environmental degradation, then what is the extent of this back reaction of environmental degradation on economic growth?

Furthermore, the interrelationships among variables in environmental and demographic systems are likely to have different consequences depending on the country's development level, and are conceivably expected to penalize the economic performance in developing countries compared to the developed ones. Our question here is: Can these interrelationships explain a considerable part of the fluctuating behaviour of economic growth across countries? In other words, if most poor countries experience greater environmental degradation than rich countries, and also experience worse health conditions, then to what extent can the gap between the rich and the poor countries be explained by these factors? In addition, if health status is one of the most important channels through which environmental degradation affects economic growth, then to what extent does air pollution, as an example of environmental degradation, threaten public health? And how much output growth can be achieved by exogenous environmental improvements through the health channel. In other words, can regulatory and abatement efforts compensate for the adverse impacts on economic growth that arise due to environment-related health problems?

In order to answer the previous questions, our method consists of simultaneously estimating the three equations for the determinants of economic growth, health capital, and air pollution, which have been individually identified in literature. In our model, we specify three sets of functional relationships and parameters, these are: the aggregate production function, the effect of environmental degradation on health as one of the fundamental aspects of human capital, and the environmental response to regulatory and abatement efforts. To the best of our knowledge, a simultaneous analysis of the interrelationships between these three variables has not been carried out in the relevant literature, despite the important implications of such analysis for policy recommendations.

Regarding estimation technique, instead of using the commonly applied single equation estimation methods, we jointly estimate a system of these three equations simultaneously. From an econometrics perspective, a joint system estimation leads to consistent and more efficient parameter estimates than estimating each individual equation separately, because it addresses the potential endogeneity of the right-hand side regressors and also the cross-equation residual correlations, especially if there is a zero- non covariance matrix of the error terms (Haavelmo, 1943[19]; Zellner, 1962; Zellner and Lee, 1995; Baltagi, 1998). In addition, Klein (1960) indicated that when estimating a system of simultaneous equations jointly, the efficiency gains obtained through the use of more powerful statistical methods, such as the Three Stages Least Square (3SLS) estimator, should not be neglected. Also, Baltagi (1998) emphasized that the 3SLS estimator, as a full information IV method, is one of the most efficient system estimators as it takes into account the zero restrictions in every equation as well as the variance-covariance matrix of the disturbances of the whole system. Therefore, we simultaneously estimate the equations of the system using the 3SLS estimator. We expect our method to point out the causal mechanisms behind variations in the growth of output per capita, and therefore by inference, the environmental policies or behavioural variables[20] that are most likely to have a significant effect on the relationship between health and per capita income. We argue that our methodology provides additional robust evidence on the role of environmental quality in driving economic growth, and in improving the information set behind policy decisions.

The rest of this chapter is organized as follows: Building upon the theoretical foundation of Chapter (1), an empirical econometric model is developed in Section (2) in order to investigate and examine the interaction between air pollution, in terms of $PM_{2.5}$ concentration, health, in terms of environment-related diseases, namely DALYs due to PM air pollution, and economic growth. This section includes the specification of the empirical model, data sources and descriptions, and the estimation methodology. Section (3) discusses the empirical findings, and Section (4) concludes and introduces some thoughts and implications relevant to the policy making process.

2. Empirical Analysis

In this section, we discuss the specification of the empirical model, data sources and description, and estimation methodology.

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[19] Haavelmo (1943) stated that "*if one assumes that the economic variables considered satisfy, simultaneously, several stochastic relations, it is usually not a satisfactory method to try to determine each of the equations separately from the data, without regard to the restrictions which the other equations might impose upon the same variables. That this is so is almost self-evident, for in order to prescribe a meaningful method of fitting an equation to the data, it is necessary to define the stochastical properties of all the variables involved (e.g., that some of them are given time series, or remain constant, etc.). Otherwise, we shall not know the meaning of the statistical results obtained. Furthermore, the stochastical properties ascribed to the variables in one of the equations should, naturally, not contradict those that are implied by the other equations*".

[20] Variables which influence the behaviour of firms and organizations towards environmental issues (e.g., environmental regulations).

2.1 Model Specification

Knowles and Owen (1997) argued that that the main advantage of using the MRW approach (Mankiw et al., 1992) in analysing growth dynamics, is that by using this method, structural growth equations for empirical estimation can be explicitly derived, and indirect estimates of the production function's parameters can be obtained. A common feature of empirical works which study the determinants of economic growth, and which also follow the MRW model, has been their focus on cross-country growth. Hoeffler (2000) indicated that the non-utilization of available information, as a result of reducing time series to a single or an average observation, is one of the limitations associated with single cross-country regressions, in addition to the potential endogeneity of the regressors, and the bias resulting from omitted variables. Islam (1995) and Acemoglu (2009) also pointed out that another major shortcoming of using cross-section analysis is that it doesn't account for country-specific and time-invariant heterogeneity. They argued that using a panel data approach takes out fixed country characteristics that might have a simultaneous effect on economic growth, and allows controlling country-specific aspects of the production function, and thus can correct the bias resulting from omitted variables in the cross-country approach. Accordingly, our empirical approach follows the MRW model[21], where the general specification[22] of the econometric growth model is to be estimated using standard panel data notation, and takes the following form:

$$\ln(y_{i,t}) = b_1 \ln(k_{i,t}) + b_2 \ln(e_{i,t}) + b_3 \ln(h_{i,t}) + b_4 \ln(env_{i,t}) + b_5 ln(n + g + \delta) + \eta_i + \varepsilon_{i,t} \quad (2.1)$$

where η_i denotes the country-specific effects, $\varepsilon_{i,t}$ refers to the error term, and the subscripts *i* and *t* denote country and time period respectively.

The dependent variable $y_{i,t}$ is the real GDP per capita. Following the MRW model, Islam (1995) and Caselli et al (1996), we use the aggregate investment to GDP ratio, $k_{i,t}$ as a proxy of saving rate, which is expected to have a positive impact on the growth rate. The term $(n + g + \delta)$ is the sum of population growth rate *n*, the rate of technological progress g, and the rate of capital depreciation, δ. Following the MRW model we assume that g equals 0.02. The coefficient of this variable is expected to have a negative

[21] Since testing for convergence is beyond the scope of this study, we have removed the relevant variable from our model.

[22] In our empirical model, we use the level of output as our dependent variable. There is evidence that the potential determinants of economic growth are very similar to those of output per capita, therefore levels regressions are not much different from growth regressions, yet more informative (for more details see Acemoglu (2009), Chapter 3.).

sign. In this equation, human capital is represented by two variables, namely education and health.$e_{i,t}$ denotes average years of schooling. We use this index as a proxy for education, and it is expected to have a positive effect on the growth rate.

Given that our aim is to investigate how environmental degradation, represented by air pollution, impacts economic growth performance through the health channel, our chosen measure of health capital $h_{i,t}$ is the DALYs due to ambient PM pollution. According to the WHO, DALYs due to ambient PM pollution are calculated[23] as the sum of the YLL due to premature mortality from Chronic Respiratory Diseases (CRD), Chronic Cardiovascular Diseases (CVD), and lung cancer, and the Years Lost due to Disability (YLD) for people living with these health condition or their consequences. Howitt (2005) and Cole and Neumayer (2006) argued that although life expectancy at birth increased significantly in developing countries over the past years, a considerable percentage of population in low-income countries still suffer from bad health conditions, which makes poor health one of the most likely factors that contributed to the disappointing growth performance of these countries. Accordingly, we expect the coefficient of this variable to have a negative sign.

One of the best ways of exploring the economic impact of environmental degradation is to consider environmental quality as a factor of production (Xepapadeas, 2003). Hence, it is hypothesized in our model, that the impact of air pollution enters into the determination of growth both directly, where $env_{i,t}$refers to air pollution in terms of ambient PM concentration (average annual emissions), and indirectly through its impact upon the health capital term, where we expect air pollution to have a negative impact on economic performance.

Equation (2.1) expresses the role that air pollution, and the associated poor health can play as key factors in hindering economic growth. The next step is to explore the extent environmental degradation contributes to these poor health conditions. Establishing the relationship between the model's explanatory variables and exposure to air pollution requires a model wherein both health capital and air pollution are explained. Therefore, our suggested model for exploring the impact of environmental degradation on economic growth consists of a system of three equations, the first of these is Equation (2.1) above. This is a structural growth equation based on the extended MRW model, which is employed to investigate both the direct and indirect impact (via poor health) of environmental degradation on economic performance. The second equation is a reduced form health equation that is used to estimate the effect of environmental

[23] ALRI in all ages, COPD in adults over 25 years, Lung cancer, in adults over 25 years, IHD in adults over 25 years, and Stroke in adults over 25 years.

degradation on the chosen measure of health capital, namely DALYs due to ambient PM pollution. The third is a reduced form of the determinants of air pollution, which is used to analyse the effect of both air pollution regulations and fuel switching, as examples of abatement efforts, on our chosen measure of air pollution, namely the concentration of PM.

Health Capital

The vast majority of empirical works on the determinants of health capital arise from the microeconomic framework about the demand of health as introduced by Grossman (1972). Although there were several attempts within the empirical literature to explore the variables that determine the evolution of health indicators, there is no definite theory on the determinants of health capital that can be applied at the macroeconomic level (Bloom & Canning, 2008). Given that the main focus of this study is estimating the impact of environmental degradation, in terms of air pollution-related diseases, on economic growth within a macroeconomic framework by using a theoretically supported growth model, along with the lack of solid theoretical premises for the factors contributing to health capital at the macro level, the suggested method is to define a reduced form model for the determinants of health capital. This empirical model introduces health capital as a function of a number of exogenous variables that have been informed by the literature.

Man-made air pollution is a complex mixture of many components with various toxicities which affect various aspects of human health. Cohen et al (2004) argued that PM concentration is the best index of this mixture, because exposure to PM air pollution has been linked consistently with serious health effects in many studies of both epidemiology and toxicology (Sandstrom et al, 2005; Bell et al, 2007; Boldo et al, 2011; Janssen et al, 2011; Atkinson et al, 2014; Takashi et al, 2015; Feng et al, 2016; Lin et al, 2016; Cohen et al, 2017). Woodruff et al (2006) found that high exposure to PM_{10} and $PM_{2.5}$ was associated with respiratory diseases and with sudden infant death syndrome. The association between exposure to fine particles and the increase in mortality risk, in addition to total and adult mortality rates, has been evident in many studies.

Pope et al (2002) and Ostro et al (2006) found that long-term exposure to PM is an important environmental risk factor for cardiopulmonary and lung cancer mortality. Many other studies on air pollutants used a lag structure[24] between exposure and effects in order to investigate the health impact of

[24] The studies listed in this review have used the lagged explanatory variables in a lag structure model in order to capture both the short and long-term health impacts of exposure to PM air pollution. Many other studies have indicated that using the lagged explanatory variables as instruments is an appropriate approach for identifying causal effects (Bellemare et al., 2015).

short-term exposure to $PM_{2.5}$ (Wong et al., 2002; Dominici et al., 2006; Martins et al., 2006; Kim et al., 2012; Lee et al., 2014). The results of these studies indicate that, daily exposure to $PM_{2.5}$ has immediate estimated effects on cardiovascular diseases, and delayed estimated effects (2 to 14 days) on respiratory diseases, and that short-term exposure to $PM_{2.5}$ increases the risk for hospital admission for cardiovascular and respiratory diseases significantly.

Aunan and Pan (2004) proposed exposure-response functions for the health effects of PM_{10} and Sulfur Dioxide (SO_2) pollution in China. Their results also indicate an association between the increase in cardiovascular and respiratory deaths, along with an increase in hospital admissions due to these diseases, associated with exposure to these pollutants. Jerrett et al (2005) emphasized that chronic exposure to $PM_{2.5}$ is significantly associated with ischemic heart disease and cardiopulmonary mortality when the effects of other social, demographic, and lifestyle confounders are taken into account.

Clancy et al (2004) and Hedley et al (2002) provided evidence for the occurrence of relatively rapid improvements in cardiovascular and respiratory outcomes after the successful implementation of air pollution reduction measures. Chay and Greenstone (2003a) found that there was a great reduction in infant mortality in the US in 1972 after changing the PM standard under the 1970 Clean Air Act Amendments (CAAA). Chay and Greenstone (2003b) emphasized that the reduction in total suspended particulates (TSPs) in the US, resulted in a 0.35 percent decline in infant mortality rate at the county level, during the period 1980-1982.

Accordingly, quantifying the magnitude of the health impacts of exposure to air pollution worldwide is of great importance, because of the significance of health in the growth process. Abegunde et al (2007) indicated that policy makers must pay more attention to the disease burden and loss of economic output which are associated with chronic diseases, mainly cardiovascular diseases, cancer, and chronic respiratory diseases. Zhang et al (2007) used an economic burden of disease analysis to assess the economic cost of exposure to PM_{10}. Their findings indicated that this loss was about 29,178.7 million US$ in 2006, he concluded that the rapid economic growth in China has resulted in high public welfare loss due to air pollution. Li et al (2016) also found that rapid economic growth, industrialization, and urbanization resulted in sever air pollution, and that the high $PM_{2.5}$ concentration was among the leading causes of deterioration of health in China.

Cohen et al (2005) demonstrated that considering only the impact of air pollution on mortality when estimating the burden of disease is likely to underestimate the true attributable burden, since there is evidence from epidemiological studies to suggest that air pollution is playing a role in the incidence of cardiopulmonary diseases, and thus will also contribute to the YLD. Their study calculated the air pollution burden of diseases, under the assumption that air pollution multiplies both incidence and mortality to the same extent, which means that the relative risk of unobserved morbidity equals the observed relative risk of mortality. Their results indicate that when taking morbidity into account, the DALYs due to cardiopulmonary diseases would increase by 20% worldwide.

Cohen et al (2017) used a population-weighted annual mean concentration of $PM_{2.5}$ in order to estimate the effect of long-term exposure to $PM_{2.5}$ on DALYs due to ambient air pollution, during the period from 1990 to 2015. Their findings emphasized that ambient $PM_{2.5}$ ranked as the fifth mortality risk factor in 2015, and that 7.6% of total global deaths, along with 4.2% of global DALYs could be attributed to exposure to $PM_{2 \cdot 5}$ in that year. They also indicated that a considerable percentage of the increase in ambient air pollution over the past 25 years can be traced back to increasing air pollution in low-income and middle-income countries, which suggests the potential for substantial health benefits from exposure reduction, especially in the most polluted countries.

Regarding the non-environmental factors affecting health status, Genberg (1992) has surveyed the literature on macroeconomics and health, and concluded that public health expenditure, female education, income, literacy rate, and high fertility, especially when associated with low income and illiteracy, can be associated with the deterioration of health outcomes, and thus these factors can be considered as the main driving forces for improving health outcomes.

Gangadharan and Valenzuela (2001) pointed out that on the country level, the overall population's health status and their well-being depend on three factors, which are the level of economic growth, the quality of physical environment, and the availability and accessibility of medical facilities. They expressed health as a function of income, environmental quality, and some non-economic variables, namely provision and access to health services, number of physicians, immunization rate, and education. Also, there is evidence from both cross sectional and long-time series studies indicating that higher levels of income are associated with better health (Hobcroft et al., 1984; Sachs and Malaney, 2002; Preston, 2007). Accordingly, per capita income needs to be included as an explanatory variable in our model. Education and nutritional status need also to be included, since there are many studies indicating that these are important determinants of health (Barro and Lee, 1994; Preston and Taubman, 1994; Elo and Preston, 1996; Schultz, 1997; Breierova and Duflo, 2004).

Based on the above, our model therefore considers DALYs due to ambient air pollution from PM, concentration of $PM_{2.5}$, exposure to $PM_{2.5}$, income, education level, government health expenditure, nutritional status, and some non-economic variables. The corresponding reduced form health equation is:

$$\ln (h_{i,t}) = b_1 \ln (p_{i,t}) + b_2 \ln (exp_{i,t}) + b_3 \ln (pop_{i,t}) + b_4 \ln (y_{i,t}) + b_5 ln(e_{i,t}) + b_6 \ln (gh_{i,t}) + b_7 \ln (nut_{i,t}) + b_8 \ln (imu_{i,t}) + b_9 \ln (ph_{i,t}) + b_{10} \ln (hos_{i,t}) + \xi_i + \mu_{i,t} \quad (2.2)$$

where ξ_i indicates the country-specific effects, $\mu_{i,t}$ refers to the error term, and the subscripts *i* and *t* denote country and time period respectively.

In this equation, we have three measures of air pollution, $p_{i,t}$, is the annual mean concentrations of $PM_{2.5}$, as a proxy for severity of air pollution in a country *i* at time *t*. This variable is expected to have a positive sign, as there is considerable evidence that greater adverse health effects are associated with higher levels of $PM_{2.5}$ concentrations. It is worth mentioning that using countries' mean values tends to underestimate both air pollutants' concentration levels and the consequent health impact of exposure, as the concentration of air pollutants is significantly higher in urban settings (Cohen et al., 2005).

Exposure to air pollution is represented by two measures. The first is $exp_{i,t}$, which represents the population-weighted annual mean concentration of $PM_{2.5}$ (annual mean concentration weighted by population living in the relevant area)[25]. This variable is expected to reflect the severity of the air pollution problem in urban areas. The second measure is the proportion of population at risk of $PM_{2.5}$ exposure $pop_{i,t}$, which is measured as the percentage of population exposed to $PM_{2.5}$ levels exceeding the WHO guideline value (25 micrograms per cubic meter) which sometimes is referred to as *"$PM_{2.5}$ Exceedance"*, where over a long period of time this variable can reflect the impact of long-term exposure to air pollution. Both measures are expected to be positively correlated with the dependent variable of DALYs due to ambient air pollution[26].

The variables of both per capita income and education are expected to have a positive effect on health, which means that it is anticipated that these variables will have a negative sign in our model. The variable $gh_{i,t}$ refers to the general government health expenditure as a percentage of the government general

[25] According to the WHO, the method of calculating this indicator is:
Exposure = SUM {(Pi/P) × Ci}, where: Ci = annual mean PM10 or $PM_{2.5}$ concentration in sub-population Pi, and P = SUM (Pi), which is the total population in cities with data.

[26] Some cross-section studies have used $PM_{2.5}$ exposure, in terms of population-weighted average ambient concentration of $PM_{2.5}$, as a measure of chronic exposure, and meanwhile used $PM_{2.5}$ exceedance, in terms of the proportion of the population in each year that is exposed to ambient $PM_{2.5}$, as a measure of acute exposure (IHME, 2019).

expenditure, where this is used as a proxy for health services availability. The nutritional status $nut_{i,t}$, is expressed by total kilocalories per capita per day. This variable is used as an indicator of the initial health status. We use several other variables in order to indicate access to health services, such as the immunization rate $imu_{i,t}$, the number of physicians $ph_{i,t}$, and the number of hospital beds $hos_{i,t}$. As all of these variables are expected to have a positive impact on health, then they are expected to have a negative correlation with our dependent variable, i.e. to appear in our specification with a negative sign.

Air Pollution

As previously discussed, the current scientific evidence suggests a considerable impact of air pollution on public health. This evidence has growingly been used on both the domestic and international levels to inform environmental policies. Furthermore, measuring the impact of air pollution on health started to become a critical component in policy discussions, and many countries are now taking more serious steps towards controlling air pollution.

Shafik (1994) pointed out that there are four determinants of environmental quality in any country. The first being the geographical factors such as climate and location. The second is per capita income, which reflects the production structure, level of urbanization, and consumption patterns of private goods. The third is the exogenous factors, such as technology, which are available to all countries and are changing over time. The fourth and final component being the policies, which reflect the importance of the environment in social decisions, and individuals' willingness to pay in order to protect the environment. On the other hand, Grossman and Krueger (1994), Islam et al (1998) and Panayotou (2003) emphasized that the main structural forces that determine environment degradation are the scale of economic activity, the composition or structure of economic activity, and the effect of income on the demand and supply of pollution abatement efforts.

A large body of literature have measured the impact of environmental regulations on air quality. Shafik and Bandyopadhyay (1992) investigated the impact of a number of policy variables on environmental quality. Their econometric results demonstrated that the policy variables are significant with respect to some specific environmental variables, such as the case of higher electricity tariffs reducing carbon dioxide emissions. Arrow et al (1995) emphasized that the absence of strict environmental regulations leads to a monotonic increase of pollution with economic growth. He also called for the imposition of limits on economic growth, in order to ensure a sustainable scale of economic activity within the ecological life-support system. Henderson (1995) investigated the impact of regulatory efforts on ground level ozone, as a measure of air quality in an industrial location, he found that local air quality regulations improved air quality measurements because of the reduction in emissions from various sources. Greenstone and Hanna (2014) assessed India's environmental regulations, they found that the effective enforcement of air pollution regulations was associated with substantial improvements in air quality, and that the increasing demand for air quality reflects that even in a weak institutional setting, a strong public support allows environmental regulations to succeed.

The literature on growth and the environment has identified income as one of the main determinants of environmental quality. Selden and Song (1994) analysed the relationship between per capita SO_2, PM, nitrogen oxides (NO_X), and carbon monoxide (CO), with both income and population density. Their results show that there is a strong positive relationship between income and air pollution. This result is consistent with the evidence from the greater body of literature on Environmental Kuznets Curve (EKC), which investigates the relationship between the stage of economic development and environmental degradation, where environmental damage first increases with income, then declines (Stern et al, 1996; Brock and Taylor, 2004; Costantini and Martini, 2006).

The relationship between population density and air pollution has been found by Selden and Song (1994) to be significantly negative. Their interpretation for this negative relationship is that when people live closer together, the emissions associated with transportation may be lower. They also identified other factors that correlated with emissions such as composition of output, the level of education, political structure, climate and geography. Panayotou (1997) found that income and population density are among the main determinants of environmental quality. In contrast with Selden and Song (1994) he found that low population densities, fewer than 50 persons per square kilometre, were associated with high ambient SO_2 levels (70 kg/km^3). His findings indicated that better environmental policy results in a significant reduction in ambient SO_2 levels, while faster growth and higher population densities result in marginally to moderately higher ambient SO_2 levels. He concluded that improving environmental policies aimed at controlling pollution can offset these effects and make economic growth more sustainable

Grossman and Krueger (1994) used a reduced form approach in order to model the structural equations relating environmental regulations, technology, and industrial composition to GDP, and then to link the level of pollution to the regulations, technology and industrial composition. Grossman and Krueger (1994) and Panayotou (1997) indicated that although there are some limitations on the use of the reduced form approach, but using this method to investigate the relationship between income levels and pollution, as an example, has been a useful step towards answering some critical questions regarding the relationship between the development stage and environmental degradation. They added that estimation using this method has many advantages in the context of investigating environmental issues, where the most important one is that this approach spares researchers the use of more difficult specifications, like structural equations, while providing a better understanding of the net effect of the explanatory variables on pollution.

Cohen et al (2004) used some kind of a reduced form model in their study in order to econometrically estimate a fixed-effects model of the concentration of urban ambient PM. Their model was based on the World Bank Global Model of Ambient Particulates (GMAPS). Their estimated equation focused on the anthropogenic sources of pollution and the capacity of the natural environment to generate, disperse and dissipate pollutants.

Accordingly, our assessment for the determinants of air pollution considers the strength of the local regulation of pollution, fuel switching, income, the scale and composition of economic activity, the intensity of energy use, and demographic and atmospheric conditions that affect the transport of pollutants. Thus, the corresponding reduced form environmental equation is:

$$\ln(p_{i,t}) = b_1 \ln(reg_{i,t}) + b_2 \ln(fs_{i,t}) + b_3 \ln(y_{i,t}) + b_4 ln(ind_{i,t}) + b_5 \ln(iea_{i,t}) + b_6 \ln(ei_{i,t}) + b_7 \ln(ec_{i,t}) + b_8 \ln(popd_{i,t}) + b_9 \ln(temp_{i,t}) + \zeta_i + v_{i,t} \quad (2.3)$$

where ζ_i indicates the country-specific effects, $v_{i,t}$ refers to the error term, and the subscripts *i* and *t* denote country and time period respectively.

The strength of air pollution regulations of a country can be measured in some different ways, where each of them has its own strengths and limitations. Several studies used energy consumption as an indicator of the effectiveness of environmental regulations. Cole and Elliott (2003) created a regulatory effectiveness measure, ranging between zero and one, in order to rank countries in terms of the strength of their environmental regulations. This energy-based index is calculated by dividing countries' energy consumption by their GDP. Other studies adopted the same energy index using other estimates of energy and alternative measures of GDP (Harris et al., 2000). These indexes have been criticized on the grounds that changes in energy use do not necessarily reflect an effectiveness of the environmental standards, as energy use may differ across countries for many other reasons, such as differences in energy prices, scale and composition of economic activities, and the degree of trade openness (Brunel and Levinson, 2013). In addition, if environmental regulations raise energy prices, energy expenditures as a share of GDP are also likely to increase.

Another way of capturing the strength of air pollution regulations in a country, is by observing the actual reduction in major pollutants such as lead, PM, SO_2, and carbon dioxide (CO_2), as these reductions can reflect the effectiveness of environmental standards in that country (Smarzynska and Wei, 2004). On the other hand, changes in emissions could be caused by changes in production, as many countries have experienced recessions and drops in their output levels during the economic crises in 1990s and 2000s. Considering that, an adjustment can be made by adjusting the reduction in emissions for the corresponding changes in GDP. In this equation, we use a dummy variable to indicate the effectiveness of environmental regulations $reg_{i,t}$, which is calculated based on the percentage of reduction in total emissions adjusted for percentage change in GDP during the study period. Reduction in emissions is taken as equal to the average percentage reduction in total emissions of CO_2, NOx, SO_2, PM and black carbon. This variable is expected to have a negative correlation with our dependent variable of concentration of PM.

NILU-Polska (2005)[27] demonstrated that abatement options are divided into technical and preventative. Preventative abatement options refer to options prior to combustion that aim at minimizing emissions, such as coal washing and fuel switching. These options either require using a better quality (cleaner) fuel within the same fuel type or switching to an alternative fuel with lower emissions. Following this, fuel switching $fs_{i,t}$,, represented by using alternative energy as a percentage of total energy use, is used as a proxy of abatement efforts. This indicator refers to clean (green) energy, or non-carbon based energy sources, that do not produce carbon dioxide when generated, such as hydropower, nuclear, geothermal, and solar powers, and this variable is expected to have a negative effect on air pollution.

The economic composition $ind_{i,t}$,, is indicated by the share of industry in GDP. Intensity of economic activities $iea_{i,t}$,, is measured as GDP per square kilometre. Energy intensity $ei_{i,t}$,, is represented by Kg of oil equivalent per \$1,000 GDP, and $ec_{i,t}$, is energy consumption per capita. All of these variables are expected to increase air pollution. The variable $popd_{i,t}$, refers to population density (people per sq. km of land area). The coefficient of this variable is expected to have a positive sign. The average temperature, $temp_{i,t}$, taken as a proxy for atmospheric conditions, as it is suggested that the concentration of secondary PM increases during heat waves (Doherty et al., 2017).

[27] Norwegian Institute for Air Research (final report for European Commission DG Environment).

2.2 Estimation Method

We estimate this model using a balanced panel data for 145 developed and developing countries over the period 1990-2015. We consider five year-time intervals in order to mitigate economic cycle effect, so each country has five observations. As a starting point, we apply our analysis to the worldwide sample of the countries for which data is available, and then we split our sample according to the countries' per capita income. We divide the countries according to their GDP per capita level in 1990 into four groups, in order to see whether the impact of environment-related diseases on economic growth is different between high, upper-middle, lower-middle, and low-income countries.

Before estimating the model, we need to cast light on the main problems associated with empirical growth regressions. The endogeneity of the regressors is probably the most important one, because the right-hand-side variables in the growth equation are typically endogenous and measured with error (Mankiw et al., 1992). Temple (1999) emphasized that when the regression includes several badly measured variables or when these variables depart from classical hypotheses, the bias can be in either direction. The omitted variables bias resulting from the omission of relevant factors that explain growth represents another difficulty. The presence of these issues implies that using the Ordinary Least Square (OLS) method would not be appropriate, as it can result in biased and inconsistent coefficient estimates. Instrumental variables (IV) techniques have been frequently used in growth regression in order to deal with the endogeneity of the regressors problem (Barro, 1996; Gallup et al., 1998; Gallup and Sachs, 2000; Sachs, 2003; Bloom et al., 2004; Rivera and Currais, 2003; Acemoglu and Johnson, 2007; Carstensen and Gundlach, 2006; Weil, 2007). Bond et al (2001) pointed out that in models that include endogenous right-hand-side variables, using IV techniques allows consistent coefficient estimates even in the presence of measurement errors.

For an instrumental variable to be valid, it must satisfy two conditions. First, it must be relevant, which means that it must be correlated with the endogenous explanatory variable, as the instruments can be either relevant or irrelevant. If an instrument is relevant, then it may have either a strong or a weak correlation with the endogenous explanatory variables. Calculating the F-statistic, for the null hypothesis that the identifying instruments do not have a joint effect in the first-stage regression, can indicate the strength of identifying instruments, where the bigger the F-statistic, the stronger are the instruments[28]. Second, the instrument should not be correlated with the error term, in other words it must be exogenous. In order to check the instruments' exogeneity, given that we have a number of instruments more than those needed to identify each equation, the Sargan-Test (Sargan, 1958) for over-identifying restrictions

[28] The typical rule of thumb is that if the first-stage F statistics is less than 10, that would indicate a weak instrument (Stock et al., 2002).

can be applied in order to test the validity of the additional instruments. Failure to reject the null hypothesis[29] means that the set of instruments can be used with an acceptable degree of confidence.

We assume that earlier values of the regressors, whether levels or growth rates, can serve as valid instruments, which obviously satisfies the first criterion mentioned above. For example, the lagged values of disability and mortality due to ambient air pollution would usually be good predictors of their current values. They also conceivably satisfy the exogeneity criterion, because in this case the regression describes the relation between the per capita income growth rate and the prior values of the explanatory variables, which disentangles the estimation from the reverse causality problem. In addition, evidence from studies that used lagged values of the endogenous variables as instruments in their estimation indicate that using this method in dealing with simultaneity bias is a satisfactory approach (Barro, 1996; Cole and Neumayer, 2006; Reed 2015). Caselli et al (1996) and Bloom et al (2004) argued that since the validity of lagged variables as instruments depends on their lack of correlation to the error term, then the Sargan/ Hansen test for over-identifying restrictions is an appropriate and reliable method for testing the presence of such correlation.

Suhrcke and Urban (2010) indicated that careful attention should be paid to the number of instruments to be used in the regression, especially when using lagged values of the regressors as instruments, as there is a trade-off between improving efficiency with using additional instruments and the exacerbation of the weak-instruments problem, if the correlation between the additional instrumental variables and the instrumented covariate is weak. Roodman (2007) referred to the problem of using too many instruments in the regressions. He emphasized that although this problem does not compromise the coefficient estimates, it can weaken the Sargan/ Hansen test, so the number of instruments must be as small as possible, and the robustness of the results must be checked.

2.3 Data Description

In this section, we illustrate the major trends and patterns in GDP per capita, air quality as indicated by $PM_{2.5}$ concentration, and burden of disease from air pollution as represented by DALYs due to ambient air pollution, across countries since 1990. In addition, we provide some descriptive statistics for the variables of main interest. The descriptive statistics for our full dataset are listed in Appendix 2B.

[29] H0: over-identifying restrictions are valid.

GDP per capita

Measuring the change in a country's economic output or the GDP growth can indicate how fast an economy is growing compared to another. Meanwhile, disparities in GDP per capita across countries can reflect the level of global inequality. Figure (2.1) illustrates that the sizeable income gap between rich and poor countries, which continues to widen, reaching more than 43,750 US$ in 2015, compared with about 17,300 US$ in 1990. In 2015, the world average GDP per capita was 10.224 US$, while the GDP per capita in many low-income countries such as Malawi, and Burundi was less than 300 US$. Global per capita GDP grew by an annual average of 1.62% during the study period. While, the global economy expanded at an annual average of 2.8% over the same period. During the 1990s of the past century, the lower-middle income group of countries had the highest increases in per capita GDP around the world, as their per capita income grew by about 3.96%. Meanwhile, in 2007 the upper-middle income group of countries has witnessed the highest rises across the world in per capita GDP growth rates, which reached about 8.11%. In 2015, about 33 countries have experienced negative growth in per capita GDP, where these were mostly low-income countries, while some other developing economies such as China and India have achieved per capita GDP growth rates well above the global average.

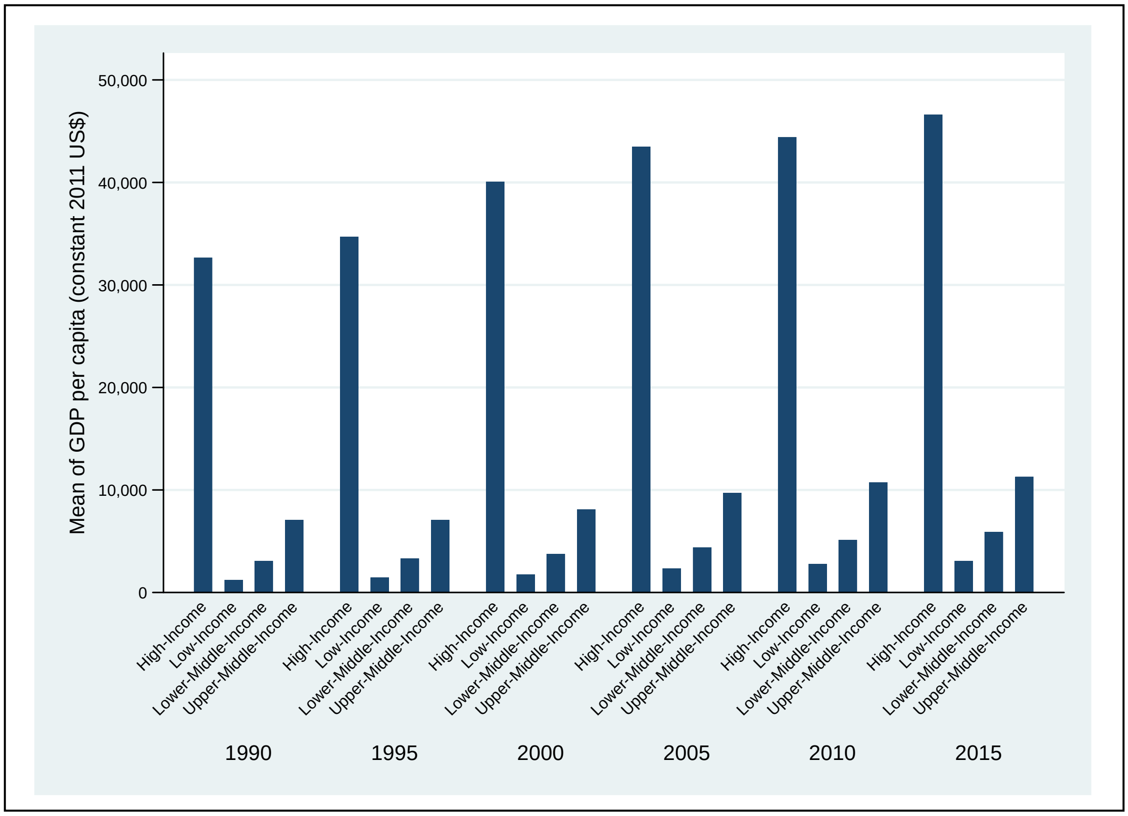


Figure (2.1): The distribution of GDP per capita by region, illustrating the income gap between rich and poor countries. Data source: World Bank database.

Fine particulate matter air pollution concentration, exposure, and exceedance

The WHO's latest data indicates that the vast majority of the world’s population lives in areas with unhealthy concentrations of air pollutants. Although many countries have witnessed some improvements in air quality during the study period, these changes have been uneven across countries. Figure (2.2) indicates that the upper-middle group of countries has witnessed slight reductions in air pollution, while low-income countries have experienced deteriorations in their air quality. In 2015, the annual exposure to $PM_{2.5}$ was highest in low-income countries, nearly as four times as its counterpart in high income countries. Meanwhile, upper and lower-middle income countries have experienced similarly high levels of exposure to $PM_{2.5}$.

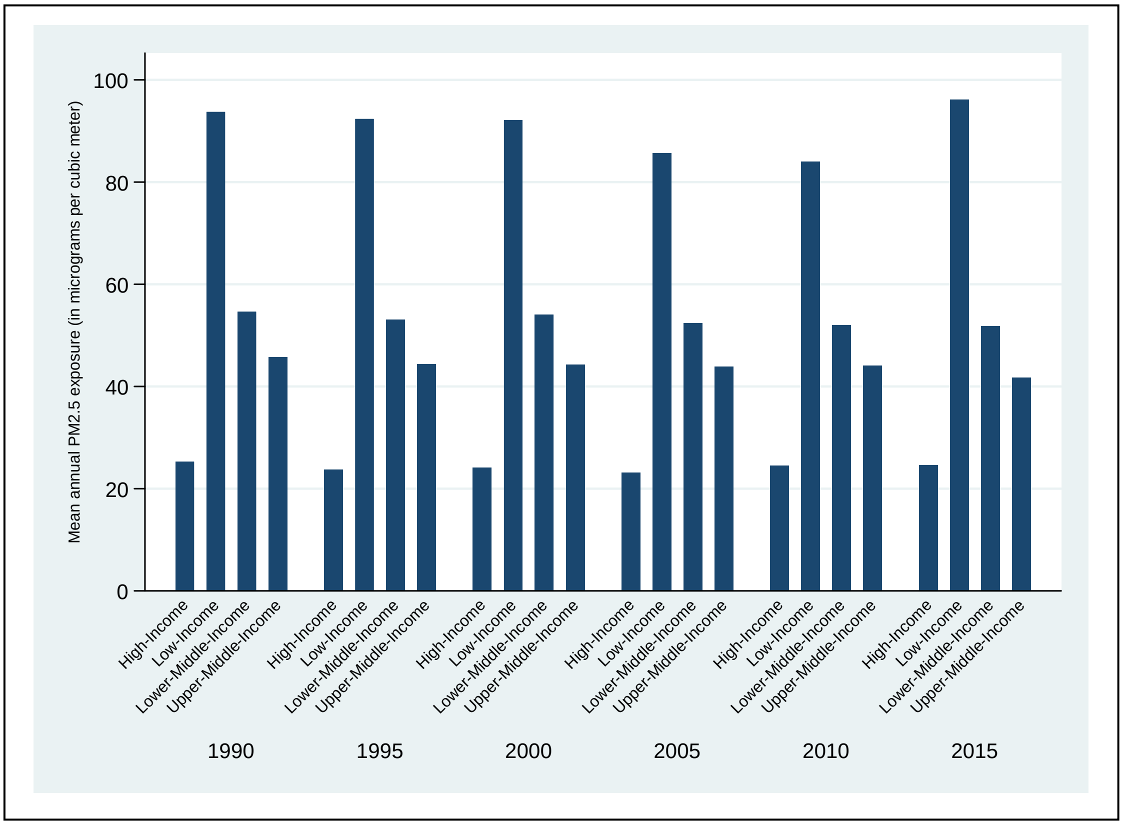


Figure (2.2): The distribution of mean annual $PM_{2.5}$ exposure by region, demonstrating the severity of air pollution in Low-income countries compared with the other groups of countries. Data source: Global Burden of Disease Study 2017. The Institute for Health Metrics and Evaluation (IHME), 2018.

Figure (2.3) illustrates that about 55% and 32% of the populations in low income and lower-middle income countries respectively, are living in areas that fail to meet even the WHO's least strict target (35 μg/m^{3}PM$_{2.5}$). Over a period of 26 years, particularly from 1990 to 2015, there was a slight decrease, from 96% to 92%, in the percentage of the world's population living in areas where the strictest WHO air quality guideline (10 μg/m^3 PM$_{2.5}$) is exceeded. This slight decline has been driven by decreases in a few of the most populous countries such as the United States and Brazil (IHME, 2019).

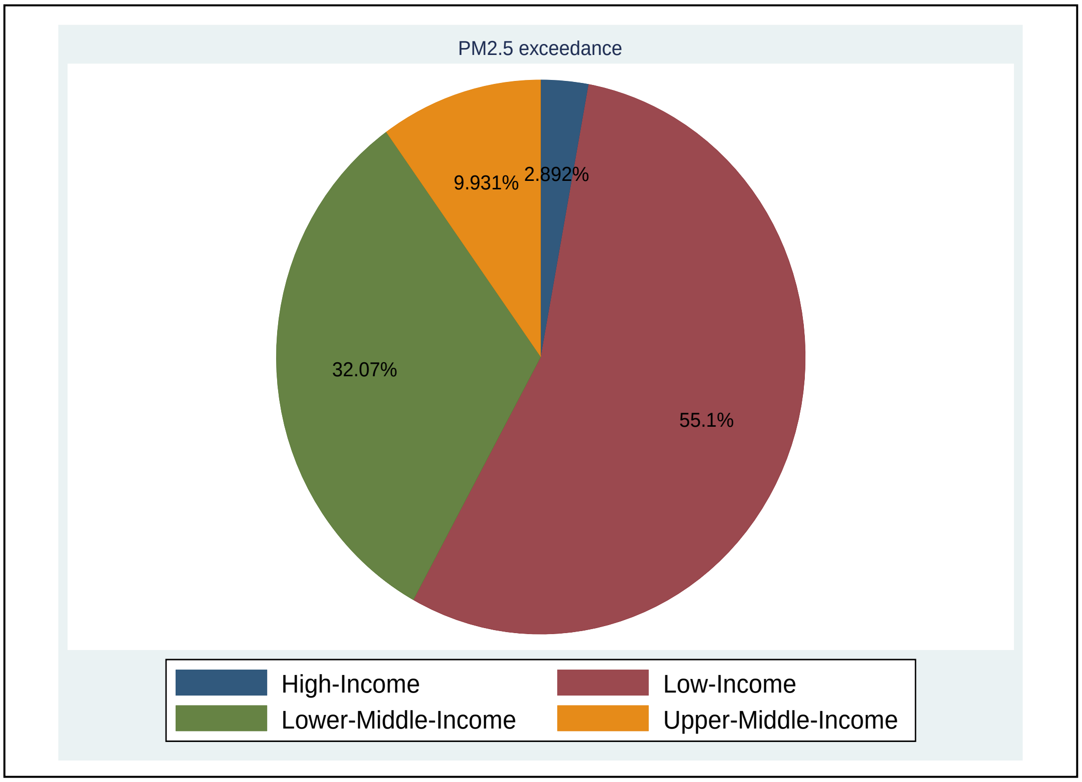


Figure (2.3): The percentage of population exposed to ambient concentrations of PM$_{2.5}$ that exceed the WHO interim Target 1 (IT-1), illustrating that a high percentage of the Low and Lower-Middle income countries are livening in places where mean annual concentration of PM$_{2.5}$ are greater than 35 μg/m3. Data source: World Bank database.

Burden of disease from fine particulate matter air pollution

Figure (2.4) shows that nearly 80% of the GBD attributable to PM$_{2.5}$ air pollution occurs in low and lower-middle income countries. The health burden from ambient PM$_{2.5}$ exposure has increased during the past few decades. During the period from 1990 to 2015, the number of deaths attributable to PM$_{2.5}$ exposure has increased by almost 68%. Exposure to high levels of ambient PM$_{2.5}$ is one of the major contributors to the decrease in life expectancy around the world. It has been estimated that in 2016, exposure to ambient $PM_{2.5}$ have reduced life expectancy by an average of 19 months in South Asia and 15 months in both North Africa and the Middle East, while this impact was far lower in the more developed countries, as it is estimated to be about 4.5 months, on average, in the high-income regions of North America and Asia Pacific.

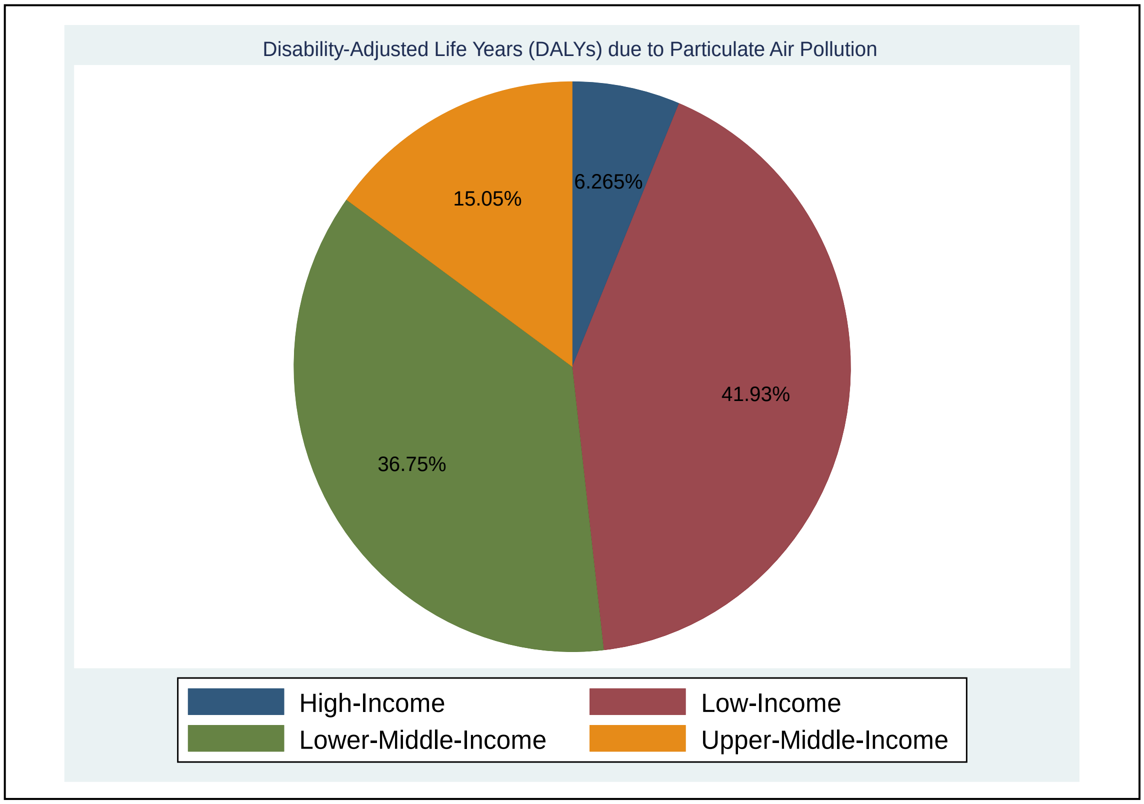


Figure (2.4): The distribution of DALYs due to particulate air pollution by region, illustrating that Low and Lower-Middle income countries bear the largest burden of diseases related to air pollution. Data source: Global Burden of Disease Study 2017. The Institute for Health Metrics and Evaluation (IHME), 2018.

Descriptive Statistics

The Tables in Appendix 2B display the basic characteristics of the data that is used in estimating our model. As mentioned earlier, our data set is balanced (145 × 6 = 870 observations for each variable)[30]. The data indicates that the average level of GDP per capita is about 11,715 US$, with a standard deviation of 17,195 US$. The DALYs due to ambient air pollution has an average of 16354 DALYs, and a standard

[30] The number of observations is 725 under the 2SLS method where the lagged values of the explanatory variables are used as instruments.

deviation of 11145 DALYs. Additionally, data on the average concentration of $PM_{2.5}$ shows that it has an average of 28.9 μg/m^3 and a standard deviation of 17.3 μg/m^3. The matrix of correlation exhibits a negative correlation between GDP per capita and poor health, along with a positive correlation between exposure to air pollution and poor health. Meanwhile, fuel switching appears to have a negative correlation with air pollution.

2.4 Data Sources

The economic outcome is measured by the per capita GDP adjusted for purchasing power parity (PPP) in constant 2011 US$. This indicator is obtained from Penn World Tables (PWT) version 9.0. Version 9.0 of the PWT covers the years 1950-2014 for 182 countries (Feenstra et al., 2015). Data on population, and on the depreciation rate is from the PWT. Investment data is from the Conference Board Total Economy Database (TED) as adjusted in November 2018. Average years of schooling is obtained from the World Development Indicator (WDI). DALYs due to ambient PM pollution per 100,000 individuals, and deaths due to ambient PM air pollution per 100,000 individuals are obtained from the WHO. Data on both concentration levels and exposure to $PM_{2.5}$, represented in the average annual concentration of $PM_{2.5}$, population-weighted average annual concentration [micrograms per cubic meter (ug/m^3)], and the proportion of population exposed to $PM_{2.5}$ are from the WDI. Total calories expressed in kilocalories per capita per day is used as a proxy for nutritional status, data for the period 2000-2013 is obtained from the Food and Agriculture Organization of the United Nations (FAOSTAT) database (FAO, 2017). Data on access to health services, such as domestic general government health expenditure (% of government general expenditure), number of physicians (per 100,000 people), number of hospital beds (per 100,000 people), and immunization (% of children ages 12-23 months) are from the WDI.

The economic composition indicated by industrial GDP (including construction), value added at constant 2011 US$ is from the WDI. Data on manufacturing share of GDP is obtained by dividing manufacturing value added by total GDP, and data on population density is from the WDI. Data on kg of oil equivalent per $1,000 GDP (in constant 2011 PPP$), as an indicator of energy intensity, and GDP per unit of energy use (in constant 2011 PPP $ per kg of oil equivalent) are from the WDI. Data on emissions intensity of black carbon, SO2, and NO_X, is available for the period 1997-2015, and is obtained from the 2018 Environmental Performance Index (EPI) Input Data Sets, prepared by the Yale Centre for Environmental Law and Policy (YCELP) in cooperation with the Centre for International Earth Science Information Network (CIESIN) of Columbia University. The scale of the economy or the intensity of economic activities, represented by GDP per square kilometer is calculated from the PWT's GDP data and the WDI data on total land area. The use of alternative and nuclear energy (% of total energy use) is used as a proxy for abatement efforts. This indicator refers to clean energy or non-carbon energy that does not produce carbon dioxide when generated, such as hydropower, nuclear, geothermal, and solar power, and data on this indicator is from the WDI.

Following Smarzynska and Wei (2004), we measure the strength of air pollution regulations by observing the actual reduction in major pollutants such as lead, PM, SO2, and CO2, and then adjust it for changes in GDP, as these reductions can reflect the effectiveness of the environmental standards in a country. Temperature data is from the Climate Data API of the World Bank. This database contains historical temperature and precipitation data aggregated from 2-degree gridded data to the country and basin levels. It is derived from the Climate Research Unit, and covers the period 1961-1999 (Mitchell et al., 2004). Although, this data set is not updated beyond 2000, there is no reason to believe that there is a significant change in countries' average temperature figures compared with the current figures. Accordingly, this dataset is used as an indicator of atmospheric conditions that affect the transport of pollutants. Data on Democracy Index is from the Freedom House.

3. Empirical Findings

We start our empirical investigation by estimating the determinants of per capita income. Given the panel nature of the data, country-specific heterogeneity should be considered in the estimation procedure. When selecting between using Fixed-effects (FE) and Random-effects (RE) approaches, an important point is to test whether the country-specific effects are correlated with the explanatory variables or not. The existence of such a correlation leads to biased estimation due to possible omitted variables, which compels an FE estimation. On the other hand, RE estimation is consistent and efficient in the absence of such correlations (Bell and Jones, 2015). Thus, a specification test is necessary in order to help selecting the better approach, and this is taken as the Hausman test (Hausman, 1978). (See results in the Appendix 2B). The result of the Hausman test shows significant differences in the estimated coefficients under both estimators. So, the null hypothesis of an RE model is rejected, and we can conclude that the FE model is a more appropriate specification for these data.

The results of the FE estimation in Table (2.1) show that, poor health retards economic performance, and that the proxy we used for environment-related diseases, is relevant in explaining economic growth within this group of countries, as the estimated coefficient of DALYs (years of healthy life lost due to disability and premature death attributable to $PM_{2.5}$ ambient air pollution) is statistically significant and has the expected negative sign. The estimated coefficients of both investment and education are significantly different from zero, and have the expected positive sign. The estimated coefficient of the term $(n + g + \delta)$, which mainly reflects population growth, is statistically insignificant, contrary to our initial expectations. In addition, the explanatory power of the regression suggests that approximately half (R^2 is nearly 53%) of the variations in the per capita income across this group of countries can be explained by differences in their saving, environmental quality, and human capital levels.

Table (2.1): The Determinants of per capita income: Fixed effects, 2SLS estimator (IV method), Full sample: (Dependent variable: log GDP per capita)

Variables	**(1) Fixed effects**	**(2) 2SLS**
log Investment	0.961**	1.163***
	(0.409)	(0.450)
log Education	0.169*	0.415**
	(0.091)	(0.170)
log DALYS	-0.661***	-0.542***
	(0.116)	(0.118)
log $PM_{2.5}$ concentration	0.479***	0.407**
	(0.168)	(0.175)
log $(\boldsymbol{n} + \boldsymbol{g} + \boldsymbol{\delta})$	0.276	0.256*
	(0.219)	(0.143)
Constant	10.375***	8.579***
	(1.660)	(1.321)
Observations	870	725
R-Squared	0.530	
Score Chi2		2.8 (p = 0.42)
Number of Countries	145	145
Country FE	Yes	Yes

Robust standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

Cole and Neumayer (2006) observed that the populations of the least developed countries (LDCs) suffer from a greater degree of poor health compared to their counterparts of the more developed countries. They argued that this association between poor health and low income can be taken as an evidence of the endogeneity of poor health in growth regressions. In addition, Deguen and Navier (2010) found that populations of poor countries, especially low socio-economic groups, experience greater health effects of air pollution. Furthermore, the omission of relevant variables from the growth regression, is a common issue when health capital enters the growth regression in the form of diseases (Bonnel, 2000; Bhargava et al., 2001; Suhrcke and Urban, 2006; de Silva and Sumarto, 2015). If these variables are positively (negatively) correlated with DALYs, the estimated coefficient of this variable would be correspondingly biased upwards (downwards) as it would include their impact. Semykina and Wooldridge (2010) pointed out that although the fixed effects estimation mitigates the endogeneity problem of this type, it is less effective in dealing with other sources of endogeneity.

In order to handle the potential problem of endogeneity of investment, education, and health in the growth equation, and in order to obtain consistent coefficient estimates, and also in order to account for the omitted variables that may contribute to the increase (decrease) in the DALYs due to ambient air pollution in a country compared to others, we use a Two Stages Least Square (2SLS) procedure that instruments the endogenous variables (Gallup et al., 1998; Gallup and Sachs, 2000; Sachs, 2003; Acemoglu and Johnson, 2007; Carstensen and Gundlach, 2006; Cole and Neumayer, 2006; Weil, 2007). We instrument investment, education and DALYs with their lagged values, in addition to the percentage of population exposed to $PM_{2.5}$ levels exceeding the WHO guideline. This latter variable reflects the severity of air pollution in each country and the consequent health impact of exposure.

The simultaneous relationship between environmental quality and per capita income has been frequently addressed in the EKC literature (Stern, 2004). A large number of these studies emphasized that democracy plays a key role in shaping the relationship between per capita income and environmental quality (degradation) (Farzin and Bond, 2005; Li and Reuveny, 2006; Buitenzorgy and Mol, 2011). With the aim of handling the endogeneity problem resulting from the bidirectional causality between environmental quality and economic growth, the $PM_{2.5}$ concentration is instrumented by its lagged value[31], in addition to democracy index. We applied several procedures for testing weak instruments. First, we tested the instrumental variables' relevance by assessing the fit of the first stage regression. We found that the explanatory power of the instruments in the first stage regression is significant. Second, the results obtained from the Sargan test support the use of these instruments. (See tests of over identifying restrictions in the Appendix 2B).

As shown in Table (2.1), the estimated coefficient of our variable of interest, DALYs due to ambient air pollution under the 2SLS estimator is larger (by about 1.2 percentage points) than its counterpart in the non-instrumented model. Also, the estimated coefficients for both education and investment are significantly larger than their counterparts in the non-instrumented model, while the estimated coefficient for population growth is the same, and the estimated coefficient of air pollution is slightly smaller.

[31] Reed (2105) pointed out that one of the best ways to avoid simultaneity bias is to use lagged values of the endogenous variable in instrumental variable estimation.

Furthermore, when comparing the results from the FE model, with those we obtained from the 2SLS estimation, we can conclude that the previous results were not produced by the endogeneity of the variables.

The results reported in Table (2.1) is very similar in magnitude to the one found by Suhrcke and Urban (2010), who investigated the growth impact of mortality due to cardiovascular diseases. In addition, the similarity of estimation results across different estimation methods has been frequently observed in the empirical studies of the impact of health on economic growth. Suhrcke and Urban (2010) did not find any significant changes between the results obtained from different estimators. Also, when they examined the impact of malnutrition on TFP, Cole and Neumayer (2006) obtained similar coefficient estimates form the wide variety of models and specifications, which they considered to be an evidence of the robustness of their results.

In order to further explore these differences in economic growth among the sub-samples and the role that environmental degradation can play in this regard both directly and through its impact on human capital, we run regressions for sub-groups of countries. The classification of countries is based on their per capita income in 1990. Group (1) includes 28 high-income countries (e.g. Switzerland, Sweden, Germany, Canada), while group (2) contains 27upper-middle income economies (e.g. Portugal, Algeria, Romania, Greece). Groups (3) and (4) include 53 lower-middle and 37 low-income economies, respectively.

Table (2.2) demonstrates estimation results for the four groups of countries under both the fixed effects and the 2SLS estimators. Estimation results for high-income countries show that the coefficient of DALYs due to ambient $PM_{2.5}$ air pollution is negative and statistically significant, which indicates a negative correlation between economic growth and poor health within this group of countries, while the coefficient of $PM_{2.5}$ concentration has a positive sign. The insignificant differences in estimation results we obtained from the FE estimator and those of the instrumented estimation, in the magnitude of all estimated coefficients, indicate the absence of endogeneity problem within this group of countries. The estimated elasticity[32] of growth with respect to poor health within this group of countries is similar under both estimators (about 4.3 to 4.6 percentage points). Furthermore, compared to the estimated coefficients of the full sample, the magnitude of the estimated coefficients of both DALYs and $PM_{2.5}$ concentration within this group of countries is significantly smaller.

[32] In these regressions, each of the estimated coefficients refers to the partial elasticity of the dependent variable with respect to the independent variable of interest, holding all other variables constant.

The 2SLS estimation results demonstrate that the elasticity of growth with respect to poor health, among upper-middle income countries is about 5.8 percentage points, nearly 1.2 percentage points higher than its counterpart of high-income countries. Contrary to our expectations, within this group of countries the estimated coefficients of both education and $PM_{2.5}$ concentration are found to be insignificant but have the correct signs. The lack of significance of some of the estimated coefficients under both the FE and the 2SLS methods, within this group of countries is likely a consequence of the small number of observations and of the limited variation in some of the variables over time.

Table (2.2): The Determinants of GDP per capita: Fixed effects, 2SLS estimator (IV method) Sub-Samples: (Dependent variable: log GDP per capita)

Variables	**High Income**		**Upper-Middle Income**		**Lower-Middle Income**		**Low Income**	
	FE	2SLS	FE	2SLS	FE	2SLS	FE	2SLS
log Investment	0.901* (0.468)	0.839** (0.392)	1.206*** (0.361)	1.998** (0.919)	0.857 (0.585)	0.540 (0.383)	1.217** (0.539)	1.823*** (0.550)
log Education	0.001 (0.114)	0.090 (0.107)	0.163 (0.144)	0.126 (0.216)	0.335** (0.142)	0.300* (0.155)	0.342 (0.243)	-0.532** (0.229)
log DALYS	-0.434*** (0.046)	-0.460*** (0.048)	-0.540*** (0.124)	-0.587*** (0.171)	-0.630*** (0.097)	-0.805*** (0.119)	-1.61*** (0.540)	-1.765*** (0.351)
log $PM_{2.5}$-concentration	0.197* (0.106)	0.243* (0.139)	-0.140 (0.252)	0.331 (0.332)	0.085 (0.184)	0.414** (0.197)	1.383*** (0.364)	1.510*** (0.291)
log $(\boldsymbol{n}+\boldsymbol{g}+\boldsymbol{\delta})$	0.176 (0.149)	0.162 (0.105)	0.513** (0.196)	0.508*** (0.178)	0.449** (0.215)	0.716*** (0.163)	-0.126 (0.250)	-0.363** (0.157)
Constant	11.654*** (0.999)	12.127*** (0.848)	12.251*** (1.505)	9.681*** (3.042)	11.555*** (1.402)	12.912*** (1.312)	12.242** (4.527)	13.477*** (2.384)
Observations	168	140	162	135	318	265	222	185
R-Squared	0.825		0.698		0.571		0.561	
Score Chi2		5.8 (p = 0.21)		6.7 (p = 0.08)		6.4 (p = 0.09)		2.5 (p = 0.64)
Number of Countries	28	28	27	27	53	53	37	37
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tests for over identifying restrictions: First- stage regression:								
Sargan (score) Chi2		4.1 (p = 0.39)		6.0 (p = 0.11)		6.6 (p = 0.08)		2.1 (p = 0.72)
Basmann Chi2		3.1 (p = 0.54)		4.6 (p = 0.20)		5.2 (p = 0.15)		1.6 (p = 0.81)

Robust standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

In addition, the estimated coefficient of DALYs within this group of countries is similar to that of the full sample under the 2SLS estimator, while it is significantly smaller under the FE estimator. As demonstrated in Table (2.2), the estimated coefficient of DALYs due to ambient $PM_{2.5}$ air pollution among lower-middle income countries is negative under both estimators, ranging between 6.3 and 8 percentage points. The magnitude of this coefficient is significantly larger than its counterparts of full sample, and both high and upper-middle income groups of countries. The estimated coefficient of $PM_{2.5}$ concentration has a positive sign, and is about 4 percentage points under the 2SLS estimator, nearly as twice as its counterpart of high-income countries. Within this group of countries, all the explanatory variables included in the regression have the anticipated signs and are significant at different levels of significance, except for the coefficient of investment, which is insignificant.

The results obtained from the 2SLS estimation indicate that the elasticity of growth with respect to poor health among low-income countries is about 17.6 percentage points. Also, within this group of countries, the estimated coefficient of $PM_{2.5}$ concentration is found to be significant and equals to 15 percentage points. The magnitude of the estimated coefficients of both DALYs and $PM_{2.5}$ concentration within this group of countries are significantly larger than their counterparts of full sample, and all other groups of countries (nearly as three times as those of the other groups). Within this group of countries, all the explanatory variables included in the regression have the anticipated signs and are significant at different levels of significance under the 2SLS estimator. The significant differences in estimation results we obtained from the FE estimator and those of the instrumented estimation, in the magnitude of most of the estimated coefficients within the low and lower-middle income groups of countries, indicate the existence of endogeneity problem within those groups of countries.

In general, our results are consistent with the results found in previous studies. We find the impact of poor health on economic growth to be negative, significant, and robust across the estimation methods we have used. The next step is to investigate the extent to which poor health can be attributed to air pollution, and the main determinants of this environmental degradation.

The results of the FE estimation for the determinants of health status are shown in Table (2.3). These results reveal that air pollution, represented by $PM_{2.5}$, has a serious negative health impact. The estimated coefficients of the $PM_{2.5}$ concentration, exposure and exceedance are statistically significant and have the expected positive correlation with DALYs due to ambient air pollution, with a larger magnitude of the estimated coefficient of exposure to $PM_{2.5}$. In addition, we found a statistically significant negative correlation between DALYs due to ambient air pollution and both income and education. The estimated coefficient of the access to health services represented by immunization level has been found significant and has a negative corelation with DALYs due to ambient $PM_{2.5}$ air pollution. While, the estimated coefficients of the availability of health services represented by the government expenditures, and the number of physicians, in addition to the initial health status in terms of nutrition, have the correct negative signs but they are statistically insignificant, contrary to our expectations. The explanatory power of the FE regression suggests that more than half (R^2 is roughly 70%) of the variations in mortality and disability due to ambient particulate air pollution over this group of countries, can be explained by differences in the severity of air pollution problem, represented by $PM_{2.5}$ concentration and exposure, income and education levels in each country.

Table (2.3): The Determinants of Health Capital: Fixed effects, 2SLS estimator (IV method), Full sample: (Dependent variable: log DALYs due to PM air pollution)

Variables	**(1)** **Fixed effects**	**(2)** **2SLS**
log $PM_{2.5}$ - concentration	0.183*** (0.053)	0.191*** (0.042)
log $PM_{2.5}$ - exposure	0.667*** (0.080)	0.629*** (0.066)
log $PM_{2.5}$ - exceedance	0.169*** (0.043)	0.147*** (0.037)
log GDP per capita	-0.337*** (0.040)	-0.445*** (0.043)
log education	-0.334*** (0.088)	-0.318*** (0.061)
log Health expenditures	-0.029 (0.023)	-0.031* (0.016)
log Immunization	-0.112* (0.067)	-0.100*** (0.032)
log Nutrition	-0.090 (0.079)	-0.075 (0.070)
log Physicians	-0.023 (0.026)	-0.003 (0.013)
log Hospitals	0.056*** (0.020)	0.044*** (0.012)
Constant	7.927*** (0.773)	8.682*** (0.674)
Observations	870	725
R-Squared	0.705	
Score Chi2		2.0 (p = 0.36)
Number of Countries	145	145
Country FE	Yes	Yes

Robust standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

In order to deal with the potential problem of the endogeneity of both income and education in the health equation, and in order to consider the omitted variables that may contribute to the increase (decrease) in the level of $PM_{2.5}$ concentration in a country compared to others, we estimate Equation (2.2) using the 2SLS method. We instrument both per capita income and education with their lagged values[33], in addition to using both per capita energy consumption and industry's share of GDP as instrumental variables for the level of $PM_{2.5}$ concentration, where these two variables can reflect both urbanization and industrialization respectively. In order to examine the validity of our instruments, we applied three procedures, first-stage regression, Sargan test, and partial Shea's R^2 statistic. The first-stage regression is a reduced form regression of the endogenous regressors on the full set of instruments. The explanatory power of the instruments in the first stage regression is significant, and Shea's partial R^2 statistic emphasizes the validity of our instruments. Also, the results obtained from the Sargan test support the use of these instruments. (See tests of over identifying restrictions in the Appendix 2B).

The estimation results under the 2SLS estimator in Table (2.3) point out the negative impact of air pollution on human health, as the estimated coefficients of $PM_{2.5}$ concentration, exposure and exceedance are highly statistically significant, and have the expected positive correlation with our health measure of DALYs due to ambient air pollution, with a larger impact of exposure to $PM_{2.5}$. Table (2.3), also shows that the 2SLS estimation results are similar to those we obtained from the non-instrumented estimation, with some differences in the magnitude of the estimated coefficients of $PM_{2.5}$ concentration, exposure to $PM_{2.5}$ air pollution, and income. The estimated coefficients for both proxies of $PM_{2.5}$ exposure are smaller than their counterparts in the non-instrumented model, while the estimated coefficient for $PM_{2.5}$ concentration is larger. In addition, the results emphasized that exposure to air pollution has more serious health impacts than the overall level of $PM_{2.5}$ concentration, as the estimated coefficients of $PM_{2.5}$ exposure are found to be larger in magnitude than those of $PM_{2.5}$ concentration under the two estimators. Similar to the results we obtained from the FE estimation, the estimated coefficients of education and income are negative and significantly different from zero. The estimated coefficient of the availability of health services represented by the government expenditures, the access to health services represented by immunization level has been found significant and has a negative corelation with DALYs due to ambient $PM_{2.5}$ air pollution under this estimator.

In order to examine the potentially different health impacts of air pollution among the different group of countries, we estimate Equation (2.2) for the four sub-samples under both the FE and the 2SLS

[33] In this case the regression describes the relation between the dependent variable and the prior values of the explanatory variables, which are education and income. These two largely determine individuals' residence, and their ability to control the quality of the environment in which they live, which subsequently affect the incidence of diseases.

estimators. Estimation results for high-income countries as shown in Table (2.4), indicate that under both estimators, the estimated coefficients of both exposure to $PM_{2.5}$ and exceedance are positive and statistically significant at different levels of significance, which indicate a positive correlation between exposure to air pollution and poor health.

Table (2.4): The Determinants of Health Capital: Fixed effects, 2SLS estimator (IV method) Sub-Samples: (Dependent variable: log DALYs due to particulate air pollution)

Variables	**High Income**		**Upper-Middle Income**		**Lower-Middle Income**		**Low Income**	
	FE	2SLS	FE	2SLS	FE	2SLS	FE	2SLS
log $PM_{2.5}$ - concentration	0.053	0.039	0.180	0.238**	0.234**	0.276***	0.150*	0.168***
	(0.124)	(0.135)	(0.109)	(0.107)	(0.096)	(0.069)	(0.087)	(0.062)
log $PM_{2.5}$ - exposure	0.465**	0.582***	0.604***	0.334*	0.350**	0.472***	0.520***	0.465***
	(0.213)	(0.141)	(0.193)	(0.173)	(0.151)	(0.123)	(0.077)	(0.076)
log $PM_{2.5}$- exceedance	0.084**	0.083**	0.101***	0.094**	0.519**	0.410**	-0.008	0.001
	(0.031)	(0.038)	(0.032)	(0.040)	(0.241)	(0.203)	(0.030)	(0.001)
log GDP per capita	-0.92***	-1.51***	-0.348***	-0.705***	-0.340***	-0.435***	-0.26***	-0.295***
	(0.122)	(0.180)	(0.086)	(0.127)	(0.068)	(0.080)	(0.031)	(0.034)
log education	-0.67***	-0.66***	-0.255*	-0.212	-0.450***	-0.310***	-0.31***	-0.31***
	(0.150)	(0.176)	(0.133)	(0.225)	(0.119)	(0.102)	(0.085)	(0.068)
log Health expenditures	-0.25**	-0.17***	-0.030	-0.052	0.016	0.011	0.020	0.003
	(0.092)	(0.056)	(0.039)	(0.058)	(0.021)	(0.017)	(0.049)	(0.027)
log Immunization	-0.111	0.174*	-0.300***	-0.122	-0.068	-0.168***	-0.070	-0.045
	(0.078)	(0.094)	(0.057)	(0.091)	(0.076)	(0.048)	(0.052)	(0.043)
log Nutrition	0.222*	-0.161	0.009	0.143	-0.316***	-0.129	0.083	0.131
	(0.114)	(0.145)	(0.175)	(0.176)	(0.111)	(0.104)	(0.092)	(0.094)
log Physicians	-0.032*	-0.021	-0.046	0.018	-0.046	-0.015	0.008	-0.011
	(0.016)	(0.023)	(0.047)	(0.029)	(0.051)	(0.027)	(0.024)	(0.017)
log Hospitals	0.224***	0.054	0.011	0.003	0.034	0.024	-0.018	-0.026*
	(0.042)	(0.053)	(0.043)	(0.027)	(0.033)	(0.020)	(0.017)	(0.016)
Constant	14.451***	23.2***	8.792***	11.265***	9.039***	8.356***	6.696***	7.199***
	(1.915)	(2.043)	(1.791)	(1.533)	(1.785)	(1.503)	(0.892)	(0.789)
Observations	168	140	162	135	318	265	222	185
R-Squared	0.918		0.804		0.715		0.784	
Score Chi2	7.5 (p = 0.02)		1.2 (p = 0.56)		1.6 (p = 0.44)		4.4 (p = 0.11)	
Number of Countries	28	28	27	27	53	53	37	37
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tests for over identifying restrictions: First- stage regression:								
Sargan (score) Chi2	5.9 (p = 0.05)		0.4 (p = 0.81)		1.1 (p = 0.58)		14 (p = 0.00)	
Basmann Chi2	4.5 (p = 0.11)		0.3 (p = 0.86)		0.8 (p = 0.66)		11 (p = 0.00)	

Robust standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

While, the estimated coefficient of $PM_{2.5}$ concentration has been found to be insignificant. The estimation results also highlight the role that income and education levels, along with the availability and accessibility of health care services can play in health status.

The estimated elasticity of DALYs due to ambient air pollution with respect to $PM_{2.5}$ exposure is approximately 5.8 percentage points under the 2SLS estimator, and the estimated coefficient of the proportion of population at risk of $PM_{2.5}$ exposure is about 0.8 percentage points. In addition, compared to the estimated coefficients of the full sample, the estimated coefficients of both $PM_{2.5}$ exposure and exceedances within this group of countries are significantly smaller.

The 2SLS estimation results indicate that the elasticity of DALYs due to ambient air pollution with respect to $PM_{2.5}$ concentration, among upper-middle income countries, is about 2.4 percentage points under the 2SLS estimator, which is larger than its counterpart of the full sample. Within this group of countries, the estimated elasticity of DALYs with respect to $PM_{2.5}$ exposure is about 3.4 percentage points, and the estimated coefficient of the proportion of population at risk of $PM_{2.5}$ exposure is roughly 0.9 percentage points. The results show that the elasticity of DALYs due to ambient air pollution with respect to $PM_{2.5}$ concentration, among lower-middle income countries, is about 2.7 percentage points under the 2SLS estimator. The estimated coefficients of both exposure to $PM_{2.5}$ air pollution and the proportion of population at risk of $PM_{2.5}$ exposure among lower-middle income countries are positive and equal to about 4.7 and 4 percentage points, respectively. The magnitude of these coefficients is significantly larger than their counterparts of both high and upper-middle income countries.

The results obtained from the 2SLS estimation indicate that the elasticity of DALYs due to ambient air pollution with respect to $PM_{2.5}$ concentration, among low-income countries, is about 1.7 percentage points under the 2SLS estimator, which is similar to this of the full sample. The estimated coefficient of $PM_{2.5}$ exposure is roughly 4.65 percentage points among low-income countries. Contrary to our initial expectations, the estimated coefficient of $PM_{2.5}$ exceedance or the proportion of population at risk of $PM_{2.5}$ exposure has been found to be insignificant. The estimation results also emphasize the role that income and education levels can play in determining health status among the low, the lower and the upper-middle groups of countries.

In general, it can be concluded that a significant part of DALYs due to cardiovascular and respiratory disease and lung cancer can be explained by exposure to $PM_{2.5}$, and that the exposure to higher concentration levels of $PM_{2.5}$ resulted in a significantly higher level of disability. In other words, a considerable part of poor health resulting from environment related diseases can be attributed to air pollution. Also, Poor health has been found to be more elastic with respect to both air pollution concentrations and exposure in developing countries than in the developed ones, which means that efforts to reduce air pollution can result in greater human capital and economic returns in these countries", given the important role that human capital plays in advancing economic growth. Therefore, controlling these environment-related diseases is of extreme importance for sustaining economic growth and ensuring humans' wellbeing. One step in this direction is to investigate the main driving forces behind the current environmental degradation in terms of air pollution.

Table (2.5): The Determinants of Air Pollution: Fixed effects, 2SLS estimator (IV method), Full sample: (Dependent variable: log $PM_{2.5}$ Concentration)

Variables	(1) **Fixed effects**	(2) **2SLS**
log Env-Regulations	-0.003** (0.001)	-0.002* (0.001)
log Fuel Switching	-0.008 (0.016)	-0.002 (0.014)
log GDP per capita	-0.033** (0.015)	-0.070*** (0.020)
log GDP Industrial	0.008*** (0.003)	0.006* (0.004)
log Int-Econ-Activities	0.055*** (0.020)	0.049** (0.020)
log Energy Intensity	0.002*** (0.000)	0.001 (0.001)
log Energy Consumption	0.034** (0.015)	0.033* (0.017)
log Population Density	0.007 (0.026)	0.028 (0.029)
log Temperature		-0.246*** (0.037)
Constant	3.256*** (0.121)	3.993*** (0.126)
Observations	870	725
R-Squared	0.117	
Score Chi2		2.1 (p = 0.15)
Number of Countries	145	145
Country FE	Yes	Yes

Robust standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

As demonstrated in Table (2.5), the FE estimation results highlight the role that the effectiveness of environmental regulations can play in reducing air pollution. Further, the results demonstrate that per capita income has a negative correlation with the concentration of $PM_{2.5}$. Meanwhile, the economic composition represented by the share of industry in GDP, energy intensity, intensity of economic activities, and energy consumption per capita are found to have a positive impact on the $PM_{2.5}$ concentration. Contrary to our expectations, the estimated coefficient of fuel switching as a proxy of abatement efforts, do have the anticipated sign but is found to be statistically insignificant within this sample of countries.

In order to handle the potential problem of the endogeneity of income in the environmental equation, we estimate the determinants of air pollution using the 2SLS method. Per capita income is instrumented by its lagged value, in addition to the democracy index. We examine the validity of our instruments by applying three procedures, first-stage regression, Sargan test, and partial Shea'sR^2 statistic. The explanatory power of the instruments in the first stage regression is significant, which indicates the validity of our instruments. In addition, the results obtained from the Sargan test support the use of these instruments. (See tests of over identifying restrictions in the Appendix 2B).

The main difference between the 2SLS estimation results and those we obtained from the non-instrumented estimation is that the estimated coefficient of per capita income is larger than its counterpart in the non-instrumented model. This magnitude indicates the role that democracy plays as one of the determinants of environmental quality or degradation. The estimated coefficients of all the variables included in this equation have the anticipated signs and are found to be significant at different levels of significance, except for the estimated coefficients of fuel switching, energy intensity, and population density, which are statistically insignificant. The estimated coefficient of the proxy for environmental regulations is smaller than its counterpart in the non-instrumented model.

In order to examine the potentially different determinants of air pollution among the different groups of countries, we estimate Equation (2.3) for the four sub-samples. Estimation results for high-income countries show that the estimated coefficients of both fuel switching and environmental regulations are negative and statistically significant, which indicate the positive correlation between air pollution and policy choices represented in abetment and regulatory efforts. The estimated elasticity of $PM_{2.5}$ concentration with respect to fuel switching within this group of countries is about 0.3 percentage points under the 2SLS estimator, as illustrated in Table (2.6). While, the estimated elasticity of $PM_{2.5}$ concentration with respect to environmental regulations is approximately 18 percentage points. The results also indicate that there is a positive correlation between $PM_{2.5}$ concentration and intensity of economic activities, population density, and average temperature.

Table (2.6): The Determinants of Air Pollution in sub-samples: Fixed effects, 2SLS estimator (IV method) Sub-Samples: (Dependent variable: log $PM_{2.5}$ Concentration)

Variables	**High Income**		**Upper-Middle Income**		**Lower-Middle Income**		**Low Income**	
	FE	2SLS	FE	2SLS	FE	2SLS	FE	2SLS
log Env- Regulations	-0.014**	-1.831***	-0.559**	-0.614***	-0.074	-5.027***	0.045	-0.185
	(0.006)	(0.228)	(0.227)	(0.159)	(0.076)	(0.746)	(0.095)	(0.207)
log Fuel Switching	-0.021*	-0.032**	-0.057**	-0.094*	0.003	0.078	0.016	-0.056
	(0.013)	(0.015)	(0.023)	(0.054)	(0.025)	(0.211)	(0.024)	(0.051)
log GDP per capita	0.157***	0.227	-0.058**	-0.634*	-0.026	0.001	0.025*	0.161*
	(0.048)	(0.263)	(0.024)	(0.372)	(0.048)	(0.025)	(0.014)	(0.095)
log GDP Industrial	0.009	0.005	-0.001	-0.006	0.007***	0.007*	0.024**	0.074*
	(0.040)	(0.056)	(0.009)	(0.014)	(0.002)	(0.004)	(0.012)	(0.043)
log Int-Econ-Activities	0.052	0.079**	0.059	0.175*	0.060*	0.066**	-0.015	-0.068*
	(0.039)	(0.040)	(0.035)	(0.106)	(0.034)	(0.032)	(0.032)	(0.036)
log Energy Intensity	-0.162***	-0.175	-0.005	0.310	0.042	-0.120	-0.005	0.003*
	(0.051)	(0.107)	(0.029)	(0.231)	(0.050)	(0.145)	(0.023)	(0.002)
log Energy Consumption	-0.000	-0.253	0.021	0.318	0.013	-0.098	0.017	-0.017
	(0.000)	(0.173)	(0.015)	(0.249)	(0.040)	(0.155)	(0.021)	(0.040)
log Population Density	0.272**	0.305***	0.039	-0.147	-0.024	0.040	-0.086**	-0.135*
	(0.123)	(0.077)	(0.072)	(0.164)	(0.030)	(0.081)	(0.038)	(0.077)
log Temperature		0.032***		0.087***		0.892***		0.881***
		(0.006)		(0.009)		(0.118)		(0.293)
Constant	1.117	2.772**	5.600***	3.887***	3.385***	-15.77***	3.650***	2.276***
	(0.724)	(1.265)	(0.833)	(1.420)	(0.493)	(2.604)	(0.314)	(0.561)
Observations	168	140	162	135	318	265	222	185
R-Squared	0.590		0.387		0.122		0.061	
Score Chi2	0.53 (p = 0.46)		0.0 (p = 0.99)		0.08 (p = 0.78)		0.07 (p = 0.78)	
Number of Countries	28	28	27	27	53	53	37	37
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tests for over identifying restrictions: First- stage regression:								
Sargan (score) Chi2	0.55 (p = 0.46)		0.0 (p = 0.99)		0.09 (p = 0.76)		0.07 (p = 0.79)	
Basmann Chi2	0.41 (p = 0.52)		0.0 (p = 0.99)		0.07 (p = 0.79)		0.05 (p = 0.82)	

Robust standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

The 2SLS estimation results indicate that the elasticity of $PM_{2.5}$ concentration with respect to fuel switching among upper-middle income countries is about 0.9 percentage points, nearly three times as its counterpart for high-income countries. In addition, the impact of environmental regulations on the concentration of air pollution is found to be negative and significant, yet the estimated coefficient within this group of countries is significantly less than its counterpart of high-income group of countries. Within this group of countries, the estimated coefficient of per capita income is roughly 6.3 percentage points and has a negative sign.

Within the lower-middle income group of countries, the estimated coefficient of environmental regulation is negative and equals about 50 percentage points. The magnitude of this coefficient is significantly larger than its counterparts for both the high and upper-middle income countries. Contrary to our expectations, the results obtained from the 2SLS estimation for low-income countries indicate that the estimated coefficients of both environmental regulation and fuel switching have been found insignificant. The estimated coefficients of all other variables included in this equation have the anticipated signs and are found to be significant at different levels of significance within this group of countries, except for the estimated coefficient of energy consumption. As shown in Table (2.6), the 2SLS estimation results for this group of countries are significantly different from those we obtained from the non-instrumented estimation, with major differences in the magnitude of almost all estimated coefficients. The previous results show that $PM_{2.5}$ concentration is more elastic with respect to abatement efforts, as represented by fuel switching, within the group of upper middle-income countries compared with the high-income group of countries. At the same time, environmental regulation seems to affect the concentration of $PM_{2.5}$ in lower middle-income countries more than the other groups of countries.

In general, our results of the single equation estimation are for the most part consistent with those reported in earlier empirical work. The lack of significance of some of the estimated coefficients under both the FE and the 2SLS methods, especially when dealing with sub-samples, is likely a consequence of the small number of observations and of the limited variation in some of the variables over time. Before coming to a conclusion, we need to address the relationship between pollution, health and economic growth more comprehensively, as the relationship between these variables is complicated and overlapped to a great extent. That can be done by estimating the three equations (2.1, 2.2, and 2.3) as a system, which we will do in the next section. In fact, the used estimation technique, whether it is a system estimation or an equation-by-equation estimation, does not change the nature of the model as simultaneous equations, and noticing that all the estimation techniques have their own strengths and limitations.

The main advantage of estimating a system of equations is reducing the probability of losing the implicit information in equation-by-equation estimation. In other words, the efficiency gains of the system estimation approach are resulting from taking into consideration cross-equation correlations of the disturbances. In addition, the system estimation automatically accounts for the endogeneity problem. However, the most important shortcoming of using this method is that the consequences of model misspecification are more detrimental than those of the equation-by-equation estimation method. To clarify this argument, when one of the equations in the system is misspecified, it can debases the entire system, and therefore all the estimated coefficients might be biased, while in the case of using the equation-by-equation estimation method, only the estimated coefficients of the misspecified equation will be biased, while the estimated parameters of the other equations will remain unaffected. It is worth mentioning that, the problem resulting from getting biased estimated coefficients is that the policymakers may be misguided by these results, thus expecting outcomes for policy intervention that are not feasible in the real world.

Accordingly, in order to estimate the regression coefficients efficiently, we apply a system estimation[34] where the 3SLS[35] estimator is used. In fact, the 3SLS is an estimation method which combines the system equations of Seemingly Unrelated Regression (SUR) with 2SLS which estimates the coefficients of each structural equation separately, thus it estimates all coefficients simultaneously (Zellner, 1962).

Comparing the outcomes of the system estimations for the full sample, as reported in Table (2.7), with their corresponding equation-by-equation estimation indicates that, the results of the system estimation are significantly different from those obtained from the equation-by-equation method. In the growth equation, the estimated elasticity of economic growth with respect to DALYs due to ambient air pollution is significantly larger than its counterpart under the single equation method, and has a lower standard error (FE: 6.6, 2SLS: 5.4, 3SLS: 7.95). Meanwhile, the estimated elasticity of economic growth with respect to the level of $PM_{2.5}$ concentration is almost unbiased under the three estimation procedures (around 4 percentage points) but has a negative sign under the 3SLS estimator. There is a significant difference in the magnitude of the estimated coefficient of investment, approximately 7 percentage points, under both methods (single and system estimations). Also, the bias in the estimated coefficient of population growth under the three estimators is nearly 16 percentage points.

Estimating the health equation in the context of the system estimation yielded estimated coefficients, with respect to signs and significance, which are similar to those obtained from the equation-by-equation

[34] It is worth mentioning that the system of equations is estimated using the 3SLS and GMM estimators considering both static and dynamic specifications of the model, in order to introduce dynamics into the system, we included a lagged dependent variable in growth equation. This way, we can distinguish both the short- and long-run effects. The estimated equations of the system for the dynamic specification also confirm the main conclusions drawn from the static model.

[35] Stata does the 3SLS using the reg3 command.

approach under the 2SLS estimator. The magnitude of the estimated coefficients under the 3SLS estimator is remarkably different from that obtained under the single equation method.

Table (2.7): System Estimation (3SLS estimator): Full Sample

Variables	**Growth Equation**	**Health Equation**	**Air Pollution Equation**
log Investment	0.489*** (0.145)		
log Education	0.032 (0.056)	-0.222*** (0.041)	
log DALYS	-0.795*** (0.064)		
log $(\boldsymbol{n}+\boldsymbol{g}+\boldsymbol{\delta})$	1.889*** (0.662)		
log $PM_{2.5}$ - concentration	-0.436*** (0.139)	0.119*** (0.036)	
log $PM_{2.5}$ - exposure		0.460*** (0.063)	
log $PM_{2.5}$ - exceedance		0.112*** (0.019)	
log GDP per capita		-0.582*** (0.043)	-0.178*** (0.023)
log Health expenditures		-0.020 (0.015)	
log Immunization		-0.073*** (0.019)	
log Nutrition		-0.061 (0.049)	
log Physicians		-0.017* (0.010)	
log Hospitals		0.039*** (0.011)	
Environ- Regulations			-0.391*** (0.071)
log Fuel Switching			0.016 (0.012)
log GDP Industrial			0.003 (0.003)
log Int-Econ-Activities			0.032** (0.014)
log Energy Intensity			0.001 (0.002)
log Energy Consumption			0.050*** (0.015)
log Population Density			0.075*** (0.020)
log Temperature			0.108* (0.060)
Constant	14.602*** (0.566)	10.541*** (0.537)	4.213*** (0.119)
Observations	870	870	870

Robust standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

These results confirm the notable positive role of both the $PM_{2.5}$ concentration, exposure and exceedance in increasing mortality and disability due to cardiovascular and respiratory diseases and lung cancer, with a larger impact of exposure to $PM_{2.5}$ than concentration. In this estimation, the estimated elasticity of DALYs due to ambient air pollution with respect to the level of $PM_{2.5}$concentration equals about 1.2 percentage points, compared to 2 percentage points under the 2SLS estimator. Meanwhile, the estimated coefficients of exposure to $PM_{2.5}$, and the proportion of population living in areas exceeding the WHO recommended level of $PM_{2.5}$ are respectively equal to 4.6, and 1, compared with 6.3 and 1.4 percentage points under the 2SLS estimator.

Estimation results support a negative correlation between poor health and both income and educational levels, as the estimated coefficients of both variables are found to be significant and negative in all specifications. The magnitude of the estimated coefficient of income under the 3SLS estimator (5.8) is significantly larger than that obtained under the 2SLS estimator. For our proxy of education, the differences in the magnitude of the estimated coefficient under the three estimation procedures is almost 1 percentage points.

Up to this point, the estimated coefficients obtained from both estimation methods are similar in their signs and significance on one hand, while being significantly different in their magnitude on the other hand. Regarding the determinants of air pollution, there was a noteworthy difference in the results obtained from the system estimation and those yielded by estimating the environmental equation separately. The elasticity of air pollution in terms of $PM_{2.5}$ concentration with respect to regulatory efforts are larger, by about 3.9 percentage points, than those obtained from equation-by-equation estimation. These results confirm the negative correlation between air pollution and per capita income, and also indicate that there is a positive association between $PM_{2.5}$ concentration energy consumption, intensity of economic activities, population density, and atmospheric conditions proxied by average temperature. Some of the other variables included in the equation, such as the economic composition represented by the share of industry in GDP, and energy intensity have shown mixed results under the two estimation methods.

The system estimations for the sub-samples (reported in Appendix 2A), indicate a dissimilarity between equation-by-equation and system of equations estimates, which means that the equation-by-equation estimates are negatively affected by the contemporaneous correlations of the error terms. Regarding the determinants of per capita income[36], these results indicate a negative correlation between economic output

[36] Air pollution in terms of $PM_{2.5}$ concentration has been found to be positively correlated with per capita income in lower-middle and low-income sub-samples, as these clusters consist mainly of countries in their early stages of development or industrialization phases.

and poor health, resulted from environmental degradation, within high income countries. Compared to the estimated coefficients for the full sample, the magnitude of the estimated coefficient of DALYs within this group of countries is significantly smaller, about 5.3 percentage points. The elasticity of per capita income with respect to poor health among upper-middle income countries is about 9.8 percentage points, or almost double its counterpart of high-income countries. In addition, compared to the estimated coefficient of the full sample, the estimated coefficient of DALYs within this group of countries is significantly larger.

The estimated coefficient of DALYs due to ambient air pollution among lower-middle income countries under the 3SLS estimator is negative and equals about 14 percentage points. Within this group of countries, the magnitude of the coefficient of DALYs is significantly larger than those of the upper-middle and high-income countries. The elasticity of growth with respect to poor health among low-income countries is about 26 percentage points, which is almost five times its counterpart in high income countries, and two times that of lower-middle income countries. Also, within this group of countries, the estimated coefficient of $PM_{2.5}$ concentration is about 31 percentage points, or nearly six times the coefficient estimated from the full sample.

For the determinants of health, the estimated coefficients of $PM_{2.5}$ exposure and exceedance within the high-income countries have been found to be positive and statistically significant at different levels of significance, and less than those of the full sample. The elasticity of DALYs due to ambient air pollution with respect to $PM_{2.5}$ concentration, among upper-middle income countries, is about 1 percentage points, compared with about 0.7 percentage points among both lower-middle and low-income countries. The estimated coefficient of the $PM_{2.5}$ exposure is roughly 6 percentage points among low-income countries, which is similar to the coefficient estimated from the full sample.

The results of estimating the determinants of air pollution using the 3SLS estimator indicate the positive correlation between air pollution and policy choices, represented by abetment and regulatory efforts. The estimated elasticity of $PM_{2.5}$ concentration with respect to environmental regulations within the high-income group of countries is about 1.2 percentage points, compared with 0.7, 3 and 10 percentage points in upper-middle, lower-middle and low-income countries, respectively. The elasticity of $PM_{2.5}$ concentration with respect to fuel switching among upper-middle income countries is nearly 0.5 percentage points, while the coefficient of this variable has been found insignificant across all other groups of countries. The previous results demonstrate that $PM_{2.5}$ concentration is more elastic with respect to regulatory efforts within the groups of lower-middle, and low-income countries, compared with the high- income group of countries. At the same time, abatement efforts seem to impact air pollution more seriously in upper-middle income countries.

Our findings indicate that the system estimator have yielded lower standard errors for the estimated parameters, which implies a higher precision, compared with the single equation method. The significance of both air pollution and the associated burden of disease, across all the specifications used, indicate that both environmental degradation and its attributed burden of disease are major factors which, if left unchecked, can retard economic growth. At the same time, lower levels of burden of diseases can be achieved by improving air quality. Our findings also demonstrate that efforts to reduce air pollution through policy intervention, such as the activation of environmental laws and legislations, and switching from reliance on polluting fuels to cleaner energy sources can result in great reductions of air pollution particularly in developing countries, and thus in greater economic and social gains.

4. Concluding Remarks

Despite the great body of empirical literature on growth determinants, up to the present time, some important potential determinants remain less investigated, such as environmental quality. Pollution, as an example of environmental degradation has always been considered as a direct by product of economic activities. While this is true to a certain extent, pollution is also conceptually similar to technology, as it affects the way in which factors of production: labour, capital, and land, interact to produce output. So, environmental degradation can be viewed as a factor of production which may impact economic activities either directly, or indirectly through the diminution of the level and the productivity of human capital.

The main focus of our work is to investigate the indirect impact of environmental degradation on economic growth via the health channel. Although the consequences of pollution on human health have long been acknowledged, it was only recently that research started linking pollution-induced diseases to particular human capital outcomes, and to explore their economic impacts. In order to capture the role of environmental degradation in determining cross-country differences in economic growth, and in order to quantify the magnitude of its potential impacts, we consider health conditions, in terms of mortality and disability attributable to ambient $PM_{2.5}$ air pollution related diseases, as the main channel through which environmental degradation, as measured by ambient $PM_{2.5}$ air pollution, can affect the growth of output.

Our methodology involves employing a model consisting of a system of simultaneous equations. In this system, a reduction in air pollution acts to improve health capital, which in turn enhances economic growth. Our findings indicate that once the role of health in driving growth is established, and the effects of air pollution on health are considered, we can then see that environmental quality does explain a considerable part of the cross-country variations in economic growth. It is worth mentioning that a single equation which includes the impact of environmental quality on growth does not capture this mechanism, and hence does not address the full dynamic of the role that environmental quality plays in fostering or retarding economic growth. We have estimated the parameters of our model using both equation-by-equation and system estimation methods, under three estimation techniques, namely, the FE, 2SLS, and 3SLS estimators. The main advantage of using the system of equations estimation method is obtaining efficient estimates. These efficiency gains rise with increasing correlations among the error terms of the different equations (Judge et al., 1988), as well as with higher multicollinearity between the regressors, and a larger sample size (Yahiya et al., 2008).

The results indicate the validity of our methodology in highlighting the causal mechanisms behind variations in the growth of output per capita. By implication, we provide a menu of the environmental policies or behavioural variables that are most likely to have a significant effect on the relationship between health and per capita income growth. Although, the FE, 2SLS and 3SLS estimates do not show a significant difference in the signs of the estimated coefficients, there are some marked differences in significance and magnitude under these three estimators. The largest differences are observed when comparing the magnitudes of the estimated endogenous variables. These findings also vindicate our use of a system approach in order to take into account the possible contemporaneous correlation of the error terms across equations. Indeed, the system estimator yielded the lowest standard errors for the estimated parameters, compared to the equation-by-equation method, and thus would imply the highest precision of all the estimates. The lack of significance of some of the estimated coefficients under both the FE and the 2SLS methods, especially when dealing with sub-samples, is likely a consequence of the small number of observations and of the limited variation in some of the variables over time.

The significance of both air pollution and the associated burden of diseases, across almost all the specifications used, can be considered as an indication that both environmental degradation and its attributed burden of diseases are significant variables, which can retard economic growth. A 1% increase in DALYs due to ambient air pollution has been found to reduce growth by approximately 8%, while a rise in the concentration of $PM_{2.5}$ by 1% can decline the growth of per capita income by about 4.4%. At the same time, lower levels of burden of diseases can be achieved by improving air quality. Quantitatively, a 1% change in the concentration of $PM_{2.5}$ lowers the levels of mortality and disability due to air pollution by about 1.2%, while a 1% reduction in exposure to $PM_{2.5}$ can result in decreasing DALYs due to ambient air pollution by nearly 4.6%. This can be taken as evidence of the significant indirect effect of controlling air pollution on the growth of per capita income.

A strong negative association has been found between mortality and disability due to polluted air, and countries' level of income. Also, higher levels of $PM_{2.5}$ concentration, has been found to be correlated with low levels of income. At the same time, exposure to air pollution has been found to have a heavy impact on developing countries compared with the developed ones, which results in higher proportions of population suffering from poor health conditions in these countries. Economic growth has been found to be more elastic with respect to both air pollution and poor health attributable to air pollution in developing countries than in the developed ones, which means that higher economic gains can be achieved from controlling air pollution, and the consequent improvements in health conditions in these countries.

Moreover, since exposure to a poor environmental quality and a heavy environmental burden of diseases across countries tends to correlate with poor economic performance and low income, this suggests some kind of a poverty trap, and raises a question regarding the opportunities of the least developed countries, where the economy mostly relies on sectors in which workers are regularly exposed to ambient conditions, such as agriculture, mining, and the construction industry, where these countries may adjust their way towards economic growth and speed up their economic performance through investment in environmental improvements.

Insights into the role that health can play as an engine to economic growth and the way air pollution affects this role requires a better understanding of several issues, such as: the health impacts of specific pollutants, the environmental hazards faced by a particular country or groups of people within a country, the sources of air pollution and why air quality continues to degrade in some places while improving in others, and the trends in economic impact of air pollution over time. Such an understanding is a critical step in informing air quality interventions, and establishing and implementing effective air pollution control policies. Our findings demonstrate that efforts to reduce air pollution through policy intervention, such as the activation of environmental laws and legislations, and switching from the reliance on polluting fuels that cause series environmental harm to cleaner energy sources, can result in great reductions of air pollution in developing countries, where higher levels of pollution are documented compared with developed nations, because the concentration levels of air pollution are more elastic in developing countries, and thus the human capital and economic returns of these procedures may be larger.

Lessons from current experiences of pollution control can be greatly informative to policy, especially in developing countries. Many countries around the world have achieved economic gains from successes in restraining ambient air pollution, and the effectiveness of many of their strategies has been proven. These strategies include establishing and enforcing air standards, and fuel efficiency standards for means of transportation, banning the use of polluting fuels in industries and economic production, and enhancing the transition to clean fuels and renewable energy sources via incentives, improving access to public transportation, and restricting access to private vehicles. However, the distributional and environmental effects of the implementation of each of these strategies should be taken into consideration, especially in developing countries, where the decision-making process is confronted with the challenge of protecting the environment and mitigating environmental hazards, while enhancing economic growth.

In short, nearly all economic activities produce air pollution, and almost all countries, with varying degrees, try to regulate it. However, much work has to be done in order to reduce air pollution and its heavy burden on public health. Although improving the health status of the population is a goal in itself, it is also one of the most important means through which long-term economic growth can be achieved. The evidence reviewed within this paper, suggests that air pollution has contributed significantly to slowing down the economic performance in many countries through its impact on health. In the least developed countries, which carry the largest burden of environmentally related diseases, air pollution remains a great barrier to economic growth, and therefore it must be addressed carefully, and integrated into mainstream development strategies and planning. Failure to identify and incorporate environmental concerns in the decision-making processes may be one of the primary causes for the current devastating situation facing developing countries.

Our evidence also suggests that environmental regulation may contribute to health improvements, and thus it can be considered as some kind of investment in human capital and economic growth as well. In other words, our work indicates the health benefits of reducing air pollution, and shows that the role which regulation can play in this regard should not be overlooked. While the analysis of regulatory approaches of air pollution is beyond the scope of this work, it is important to underline that effective environmental policies require careful calculations of all costs and benefits from pollution reduction, a cost-benefit analysis for policy interventions could be extremely informative in this respect.

Appendix (2A): System Estimation for Sub-samples

Table (2A.1): System Estimation (3SLS estimator): High-Income Countries

Variables	**Growth Equation**	**Health Equation**	**Air Pollution Equation**
log Investment	0.470**		
	(0.194)		
log Education	0.216***	-0.497***	
	(0.074)	(0.097)	
log DALYS	-0.536***		
	(0.032)		
log $(\boldsymbol{n}+\boldsymbol{g}+\boldsymbol{\delta})$	0.060		
	(0.067)		
log $PM_{2.5}$ - concentration	0.175	0.020	
	(0.121)	(0.077)	
log $PM_{2.5}$ - exposure		0.333***	
		(0.118)	
log $PM_{2.5}$ - exceedance		0.043**	
		(0.021)	
log GDP per capita		-1.399***	-1.367***
		(0.072)	(0.302)
log Health expenditures		-0.125***	
		(0.037)	
log Immunization		-0.053	
		(0.049)	
log Nutrition		0.079	
		(0.080)	
log Physicians		-0.018	
		(0.015)	
log Hospitals		0.118***	
		(0.029)	
Environ- Regulations			-1.207***
			(0.459)
log Fuel Switching			0.046
			(0.030)
log GDP Industrial			-0.042
			(0.073)
log Int-Econ-Activities			-0.015
			(0.058)
log Energy Intensity			-1.077***
			(0.281)
log Energy Consumption			1.259***
			(0.304)
log Population Density			0.346***
			(0.096)
log Temperature			-0.699***
			(0.140)
Constant	13.084***	20.267***	17.211***
	(0.554)	(0.985)	(3.111)
Observations	168	168	168

Robust standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

Table (2A.2): System Estimation (3SLS estimator): Upper-Middle Income Countries

Variables	**Growth Equation**	**Health Equation**	**Air Pollution Equation**
log Investment	0.459* (0.263)		
log Education	0.131 (0.106)	-0.199** (0.084)	
log DALYS	-0.975*** (0.091)		
log $(\boldsymbol{n}+\boldsymbol{g}+\boldsymbol{\delta})$	4.01*** (1.405)		
log $PM_{2.5}$ - concentration	0.413 (0.314)	0.117** (0.058)	
log $PM_{2.5}$ - exposure		0.571*** (0.138)	
log $PM_{2.5}$ - exceedance		0.050*** (0.018)	
log GDP per capita		-0.621*** (0.053)	-0.101** (0.051)
log Health expenditures		-0.020 (0.035)	
log Immunization		-0.153*** (0.048)	
log Nutrition		-0.026 (0.123)	
log Physicians		-0.041* (0.024)	
log Hospitals		-0.001 (0.021)	
Environ- Regulations			-0.07** (0.003)
log Fuel Switching			-0.050** (0.023)
log GDP Industrial			-0.005 (0.008)
log Int-Econ-Activities			0.063** (0.030)
log Energy Intensity			-0.026 (0.039)
log Energy Consumption			0.033 (0.031)
log Population Density			0.063 (0.044)
log Temperature			-0.206*** (0.054)
Constant	13.631*** (0.947)	10.992*** (1.049)	4.246*** (0.465)
Observations	162	162	162

Robust standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

Table (2A.3): System Estimation (3SLS estimator): Lower-Middle Income Countries

Variables	**Growth Equation**	**Health Equation**	**Air Pollution Equation**
log Investment	0.044 (0.181)		
log Education	0.390*** (0.102)	-0.311*** (0.059)	
log DALYS	-1.389*** (0.078)		
log $(\boldsymbol{n} + \boldsymbol{g} + \boldsymbol{\delta})$	1.123 (0.937)		
log $PM_{2.5}$ - concentration	0.515** (0.213)	0.068* (0.036)	
log $PM_{2.5}$ - exposure		0.278*** (0.105)	
log $PM_{2.5}$ - exceedance		0.000 (0.001)	
log GDP per capita		-0.664*** (0.030)	0.036 (0.065)
log Health expenditures		0.005 (0.011)	
log Immunization		-0.009 (0.014)	
log Nutrition		-0.055 (0.043)	
log Physicians		-0.011 (0.010)	
log Hospitals		0.006 (0.010)	
Environ- Regulations			-0.307** (0.133)
log Fuel Switching			0.011 (0.015)
log GDP Industrial			0.008** (0.004)
log Int-Econ-Activities			0.049* (0.026)
log Energy Intensity			-0.098* (0.052)
log Energy Consumption			-0.032 (0.046)
log Population Density			0.036 (0.039)
log Temperature			0.126 (0.096)
Constant	17.374*** (0.995)	12.535*** (0.643)	3.239*** (0.323)
Observations	318	318	318

Robust standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

Table (2A.4): System Estimation (3SLS estimator): Low-Income Countries

Variables	**Growth Equation**	**Health Equation**	**Air Pollution Equation**
log Investment	0.421** (0.019)		
log Education	0.778*** (0.112)	-0.281*** (0.034)	
log DALYS	-2.610*** (0.153)		
log $(\boldsymbol{n}+\boldsymbol{g}+\boldsymbol{\delta})$	-0.099 (0.072)		
log $PM_{2.5}$ - concentration	3.193*** (0.308)	0.071** (0.034)	
log $PM_{2.5}$ - exposure		0.612*** (0.073)	
log $PM_{2.5}$ - exceedance		0.002** (0.001)	
log GDP per capita		-0.374*** (0.022)	0.134*** (0.049)
log Health expenditures		0.006 (0.013)	
log Immunization		-0.005 (0.016)	
log Nutrition		0.029 (0.039)	
log Physicians		0.004 (0.007)	
log Hospitals		-0.008 (0.008)	
Environ- Regulations			-1.047*** (0.098)
log Fuel Switching			0.004 (0.024)
log GDP Industrial			0.057** (0.023)
log Int-Econ-Activities			-0.035 (0.026)
log Energy Intensity			-0.063* (0.035)
log Energy Consumption			-0.030 (0.029)
log Population Density			-0.110*** (0.031)
log Temperature			0.053 (0.046)
Constant	14.578*** (1.341)	6.917*** (0.463)	4.020*** (0.161)
Observations	222	222	222

Robust standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

Appendix (2B): Data, Samples, and Tests

(1) Data Description

Table (2B.1): Summary of the Data

Variable	N	Mean	Std. Dev.	Unit
GDP per capita	870	11715	17195	Constant 2011 US$
Disability due to Respiratory and Cardiovascular Diseases	870	20.3	6.185	% of all DALYs
DALYs due to ambient PM air pollution	870	1635.4	1114.5	DALYs
Age- Standardized rate of DALYs due to ambient $PM_{2.5}$	870	0.095	0.053	% of DALYs due to ambient $M_{2.5}$
Age- Standardized DALYs due to ambient $PM_{2.5}$	870	47045	19049	DALYs
Annual mean concentration of $PM_{2.5}$	870	28.941	17.318	$\mu g/m^3$
Annual average concentration of $PM_{2.5}$	870	29.817	20.18	$\mu g/m^3$
Population exposed to $PM_{2.5}$ levels exceeding WHO guideline value	870	92.80	23.63	% of total population
Proportion of population exposed to $PM_{2.5}$ levels exceeding WHO Interim Target-1 value	870	25.737	37.845	% of total population
Population-weighted average annual $PM_{2.5}$ exposure	870	55.38	42.61	$\mu g/m^3$
The use of alternative and nuclear energy	870	6.65	9.66	% of total energy use Kilotons
Population growth	870	1.44	1.285	%
Average years of schooling	870	7.1816	3.206	Years
Depreciation rate	870	0.0455	0.0118	%
Investment	870	3.23	2.18	Constant 2011 US$
Investment rate	870	5.291	1.313	% of GDP
Nutrition	870	2722	500.5	Kilocalories
Physicians	870	1.66	1.48	Per 1000 people
Hospitals beds	870	3.646	3.314	Per 1000 people
Immunization	870	70.113	21.69	% of children ages 12-23 months
Domestic general government health expenditure	870	9.9	4.55	% of government expenditure
Kg of oil equivalent per $1,000 GDP	870	2.30	4.82	Kg of oil equivalent
Manufacturing share of GDP	870	0.0998	0.2044	% of GDP
Industrial share of GDP (including construction)	870	1.12	3.75	% of GDP
NO_X emissions	870	560	1963.6	Kilotons
SO2 emissions	870	640.8	2461.3	Kilotons
Black carbon emissions	870	27.792	112.46	Kilotons
GDP per unit of energy use	870	8.15	14.08	Constant 2011 US$
Population density	870	162.8	523.85	Population per square kilometer
Energy Consumption per capita	870	2002	2129	Kg of oil equivalent per capita
Intensity of economic activities	870	98.96	1.22	GDP per square kilometer
Average temperature	870	17.3	8.5	Degree

Table (2B.2): Matrix of Correlations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) log GDP per capita	1						
(2) log DALYs	-0.8299	1					
(3) log $PM_{2.5}$ Concentration	-0.6695	0.8101	1				
(4) log $PM_{2.5}$ Exposure	-0.7176	0.7994	0.8732	1			
(5) log $PM_{2.5}$ Exceedance	-0.3477	0.4692	0.5190	0.4314	1		
(6) log Fuel Switching	0.4236	-0.4563	-0.3839	-0.392	-0.1839	1	
(7) Environmental Regulations	0.7993	-0.8022	-0.5966	-0.6561	-0.2593	0.4249	1

Table (2B.3): Hausman Test (Fixed-Random Effects), Full Sample: Growth Equation

Variables	**Fixed**	**Random**	**Difference**	**S.E.**
log Investment	0.9611558	0.2890241	0.6721318	0.1101054
log Education	0.1694991	0.3506936	-0.1811945	0.0060082
log DALYS	-0.6609795	-0.6235054	-0.0374741	.
Log PM concentration	0.4791527	-0.3673083	0.846461	0.0903714
log $(\boldsymbol{n}+\boldsymbol{g}+\boldsymbol{\delta})$	0.2762598	0.3234304	-0.0471706	.
Chi2 56.72				
Prob > Chi2 0.0000				

Table (2B.4): Tests for over identifying restrictions, First- stage regression summary statistics, Full Sample: Growth Equation

Variables	**Shea's Adj. Partial R-sq**	**Partial R-sq**	**F-Statistics**	**Prob > F**
log Investment	0.254	0.250	192.5	0.000
log Education	0.180	0.289	234.8	0.000
log DALYS	0.270	0.627	968	0.000
log $PM_{2.5}$ concentration	0.465	0.533	163.2	0.000
Sargan (score) Chi2	2.4 (p = 0.49)			
Basmann Chi2	1.9 (p = 0.59)			

Table (2B.5): Tests for over identifying restrictions, First- stage regression summary statistics, Full Sample: Health Equation

Variables	**Shea's Adj. Partial R-sq**	**Partial R-sq**	**F-Statistics**	**Prob > F**
log GDP per capita	0.577	0.592	274.4	0.000
log Education	0.744	0.787	210	0.000
Sargan (score) Chi2	2.0 (p = 0.36)			
Basmann Chi2	1.6 (p = 0.45)			

Table (2B.6): Tests for over identifying restrictions, First- stage regression summary statistics, Full Sample: Air Pollution Equation

Variables	**R-sq.**	**Adjusted R-sq.**	**Partial R-sq.**	**F-Statistics**	**Prob > F**
log GDP per capita	0.993	0.991	0.521	308.8	0.0000
Sargan (score) Chi2	2.12 (p = 0.14)				
Basmann Chi2	1.7 (p = 0.19)				

(2) Data Splitting (Sub-samples according to Income level in 1990)

1. High-Income Countries [37](>$6000)

Country	**Code**	**Country**	**Code**
Australia	AUS	Japan	JPN
Austria	AUT	Luxembourg	LUX
Belgium	BEL	Malta	MLT
Brunei Darussalam	BRN	Netherlands	NLD
Canada	CAN	New Zealand	NZL
Cyprus	CYP	Norway	NOR
Denmark	DNK	Russian Federation	RUS
Finland	FIN	Saudi Arabia	SAU
France	FRA	Spain	ESP
Germany	DEU	Sweden	SWE
Iceland	ISL	Switzerland	CHE
Ireland	IRL	United Kingdom	GBR
Israel	ISR	United States	USA
Italy	ITA	Slovenia	SVN

2. Upper-Middle Income Countries [38]($3000 > $5999)

Country	**Code**	**Country**	**Code**
Algeria	DZA	Portugal	PRT
Argentina	ARG	Republic of Korea	KOR
Azerbaijan	AZE	Romania	ROU
Belarus	BLR	Saint Lucia	LCA
Bulgaria	BGR	South Africa	ZAF
Fiji	FJI	Suriname	SUR
Gabon	GAB	Trinidad and Tobago	TTO
Georgia	GEO	Uruguay	URY
Greece	GRC	Venezuela (Bolivarian Republic of)	VEN
Grenada	GRD	Estonia	EST
Hungary	HUN	Croatia	HRV
Iran (Islamic Republic of)	IRN	Serbia	SRB
Iraq	IRQ	Czech Republic	CZE
Kazakhstan	KAZ		

[37] Number of countries is 28.
[38] Number of countries is 27.

3. Lower-Middle Income Countries [39]($500 > $2999)

Country	Code	Country	Code
Albania	ALB	Morocco	MAR
Angola	AGO	Namibia	NAM
Armenia	ARM	Nicaragua	NIC
Bolivia (Plurinational State of)	BOL	Panama	PAN
Botswana	BWA	Paraguay	PRY
Brazil	BRA	Peru	PER
Cameroon	CMR	Philippines	PHL
Chile	CHL	Poland	POL
Colombia	COL	Senegal	SEN
Congo	COG	St. Vincent and the Grenadines	VCT
Costa Rica	CRI	Tajikistan	TJK
Côte d'Ivoire	CIV	Thailand	THA
Dominican Republic	DOM	Tunisia	TUN
Ecuador	ECU	Turkey	TUR
Egypt	EGY	Turkmenistan	TKM
El Salvador	SLV	Ukraine	UKR
Gambia	GMB	Uzbekistan	UZB
Guatemala	GTM	Zimbabwe	ZWE
Honduras	HND	Latvia	LVA
Jamaica	JAM	Lithuania	LTU
Jordan	JOR	Bosnia and Herzegovina	BIH
Kyrgyzstan	KGZ	TFYR of Macedonia	MKD
Lebanon	LBN	Slovakia	SVK
Malaysia	MYS	Republic of Moldova	MDA
Mauritius	MUS	Djibouti	DJI
Mexico	MEX	Maldives	MDV
Mongolia	MNG		

[39] Number of countries is 53.

4. Low-Income Countries [40](< $500)

Country	Code	Country	Code
Bangladesh	BGD	Mozambique	MOZ
Benin	BEN	Myanmar	MMR
Burkina Faso	BFA	Nepal	NPL
Burundi	BDI	Niger	NER
Central African Republic	CAF	Nigeria	NGA
Chad	TCD	Pakistan	PAK
China	CHN	Rwanda	RWA
Equatorial Guinea	GNQ	Sierra Leone	SLE
Ethiopia	ETH	Singapore	SGP
Ghana	GHA	Sri Lanka	LKA
Haiti	HTI	Sudan (Former)	SDN
India	IND	Togo	TGO
Indonesia	IDN	U.R. of Tanzania: Mainland	TZA
Kenya	KEN	Uganda	UGA
Lesotho	LSO	Viet Nam	VNM
Madagascar	MDG	Yemen	YEM
Malawi	MWI	Zambia	ZMB
Mali	MLI	Cambodia	KHM
Mauritania	MRT		

[40] Number of countries is 37.

Chapter 3

The Relationship between Population and the Environment and its Impact on Sustainable Development in Egypt[41]

1. Introduction

The Rio Declaration, agreed at the United Nations Conference on Sustainable Development (UNCSD) held in 1992 at Rio de Janeiro, Brazil, as well as 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 center of sustainable development:

"Human beings are at the center 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 means to ensure human wellbeing, 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, 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

[41] Ghanem, S.K. (2018). The relationship between population and the environment and its impact on sustainable development in Egypt using a multi-equation model. *Environment, Development and Sustainability*, 20: 305–342.

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 model 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-Equations Models* (MEM) may be more appropriate to describe and analyze 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* for the environmental, social, and economic dimensions of sustainable development needs to be developed.

This study 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 analyze 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 to 2010.

Egypt Background

As shown in Figure (3A.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).

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[42] (World Bank, 2015a). The annual growth rate for the Egyptian population[43] is predicted to remain over 2%[44] 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 to 2010 (UN, 2015). Egypt's population is very large in relation to the country's limited natural resources and the rapid population growth have 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 Figure (3A.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).

[42] This study has been published earlier (in 2018), the current figure is 102.3 million.

[43] In general, there can be some other factors which affect population growth in a country, and hence the pressure on its natural resources, such as migration and mortality due to conflicts. Although the Middle East area has witnessed many conflicts and political instabilities during the study period, in particular since 2011, Egypt still had a low net migration rate (-0.39), and mortality due to conflict was probably also insignificant.

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

Overall, it is estimated that approximately 25% of the total population of Egypt live in slums[45] under poor living conditions and inappropriate housing. The number of slum areas in Egypt is estimated to be around 1221 areas[46], 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 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.

Climate Change and Air Pollution: *a*ir 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 PM, and carbon dioxide (WHO, 2010a). Egypt globally ranks 31st in terms of its contribution towards total Green House 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 tons 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 to 2008 (UNDP, 2013). Although Egypt's contribution to the global GHG emissions is relatively limited (about 0.6%[47] of total global GHG), its vulnerability to the effects of climate change is high (Smith et al., 2013; Abou-El-Naga, 2015).

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 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.

WHO (2010a) reported that the total burden of disease in 2008 was 172 DALYs[48] lost per 1000 people. 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

[45] 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).

[46] 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).

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

[48] DALYs for a disease or health condition are calculated as the sum of the YLL due to premature mortality in the population and the YLD for people living with the health condition or its consequences.

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 GDP (World Bank, 2002).

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 hours 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 number of informal workers, 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 hours per week on average, and 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).

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[49], could be devastating for the country's future. Therefore, Egypt seriously needs to follow a growth model in which economic, 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 second and third sections, 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.

[49] Although Egypt suffers from many environmental problems other than air pollution, such as water pollution, loss of fertile land, soil contamination and degradation, and poor waste management, air pollution is considered to be the most strongly related to serious economic and health impacts. For example, the cost per capita due to ambient air pollution in the Greater Cairo metropolitan area alone is seven times higher than the cost per capita due to inadequate water and sanitation nationwide (World Bank, 2019). In addition, the mortality burden due to $PM_{2.5}$ air pollution is about 1192 deaths for each 100,000 persons, compared to about 150 deaths for each 100,000 persons due to water-born diseases caused by water pollution (CAPMAS).

Then, the model specifications, data sources and variables are discussed in the fourth section. The major findings of the study are reported in the fifth section. Finally, I conclude with some thoughts and implications relevant to policy making in the sixth section.

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, 2001a).

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 emerging 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' behavior 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*[50], 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 analyze 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).

On the micro level, 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).

[50] *Multiplicative* approaches will be discussed later in more details.

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., 2007). *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; Motesharreia, et al., 2014; Uehara, et al., 2015).

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. 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):

$Impact = Population \times Affluence \times Technology$ 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):

$$\sigma^2_I = \sigma^2_P + \sigma^2_A + \sigma^2_T + 2\ COV_{PA} + 2\ COV_{PT} + 2\ COV_{AT}$$

According to this model, the sum of ($\sigma^2_P + 2COV_{PA} + 2COV_{PT}$) represent 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[51] 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 *Non-Parametric* 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., 2007). 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

[51] Or any other type of environmental degradation.

emissions, and the impact of the environmental degradation, represented by air pollution, on population in terms of public health and labour productivity:

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

Several empirical studies have pointed out the roles of the size and growth of population in increasing emissions. For example, 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 years 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 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 macro level to analysis at the micro level.

(b) 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 GBD can be traced directly to deterioration of the environment. Also, it reports that air pollution in urban areas is associated with excess morbidity and mortality, where overcrowding and inadequate housing contribute to respiratory diseases. Von Hilderbrand (2009) indicated that air pollution is associated with respiratory and cardiopulmonary diseases and death. The UNFPA (2001) reported that air pollution, both outdoors and indoors, kills between 2.7 to 3 million people every year, about 90% of them in developing countries. According to that report, outdoors air pollution harms more than 1.1 billion people around the world, and directly causes death to about half a million people per year[52], 30% of them are in developed countries' cities. Indoors air pollution affects about 2.5 billion people, most of them 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 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. Air pollutants, including gases such as carbon dioxide, nitrogen dioxide, and sulfur dioxide, along with suspended PM, have negative effects on health. Sulfur 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 suspended PM is responsible for about 3 million deaths each year. Lead, which is a component of suspended PM, is associated with reduced intelligence, impaired mental development, reduced birth weight, and disturbances of the nervous system. Aluminum 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[53]. According to the report, high temperatures associated by 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).

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.

[52] Global estimates of mortality due to outdoor air pollution range between 200 to 570 thousand, which represent about 0.4 to 1.1% of total annual deaths, and indoor air pollution has been proved to be more lethal than outdoor air pollution (World Bank, 2000).
[53] Currently, chronic diseases and mental health problems caused by climate change and air pollution are ranked at the top in the calculation of the GBD (IHME, 2019).

Communicable diseases spread faster under rising temperatures caused by global warming and climate change. The WHO (2008) illustrated that high temperature have 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. 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.

Economic and social factors such as education and income, which largely determine the individual's residence, and their ability to control the quality of the environment in which they live, 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 (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 (EEA) (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 (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 (for example, 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. As 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* is developed. Recursive models are hierarchical as all causal effects are "unidirectional" in nature (Dixon, 1999). In this type 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, 2013). This system contains three equations to describe and analyze 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 generic form:

$$Y_1 = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \varepsilon \qquad (1)$$

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.

$$Y_2 = \beta_0 + \beta_1 Y_1 + \beta_2 x_4 + \beta_3 x_5 + v \quad (2)$$

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.

$$Y_3 = \delta_0 + \delta_1 Y_2 + \delta_2 x_5 + \delta_3 x_6 + \theta \quad (3)$$

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 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, 1967; Heim, 2009; Lis, 2013), thus the regression equation takes the following form:

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

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, 1967). Autocorrelation is another important problem associated with using a time series dataset. 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 (ML) 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[54] 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:

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

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).

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

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

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

Finally, Equation (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).

[54] Using differenced data.

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 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 (Barto n, 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: 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, 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). 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 associate 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 $1,000 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: 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. 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: the total annual emissions of carbon dioxide (*I*), as an indicator of air pollution, where the increase in carbon dioxide emissions is expected to increases 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: 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, mining, etc) 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[55] and air pollution

[55] 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.

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 the poor health (*H*), as defined above, where the poor health is expected to decrease the labour productivity. The second variable is the TFP (*F*), as an indicator of technical progress, where it is expected that a higher TFP 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 (3A.1) gives the definitions of all variables included in these three equations.

4.3. Data

The data used in this study is a time series data set for the Egyptian economy during the 1960- 2010 period, this set includes 10 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 WDI, World Bank database.

Health data is 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 is 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 was collected from a Doctoral Thesis about analyzing 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) was 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 was 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 Index for some years especially during the 1960s period. Accordingly, the Education Index has been calculated for the missing years, fortunately the primary data needed for the calculation is available. Education Index is obtained out of two sub-indices, the adult literacy rate and gross enrollment rate, with relative weights of 2/3 and 1/3, respectively.

The data of total hours worked was collected from two main sources. Data for the period of 1960-1999, is drawn from 5 unpublished labour force surveys made by the Arab Labour organization (ALO), League of Arab States[56]. For the period of 2000- 2010 the data was obtained from the Egyptian Central Agency for Public Mobilization and Statistics (CAPMAS) database. The data of the real GDP per hour worked for the period of 1960-2010 is calculated by dividing the annual GDP (constant at $2000) by the annual hours worked.

The 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 comes from The Conference Board (TCB) Total Economy database. The TFP data for the period of 1960-1989 has 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 dataset used is from the WDI, World Bank database. Thus, the TFP has been measured using the following formula:

$$TFP_t = O_t / M^{\alpha}_t K_t^{(1-\alpha)}$$

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.

5. Results

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

5.1. Descriptive Statistics

Figure (3A.3)[57] 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.

[56] 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.

[57] Figures and Tables of this chapter are reported in Appendix 3A.

Figure (3A.4) shows the energy intensity[58] 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 to 2010.

Figure (3A.5) illustrates that population size has doubled during the study period. However, the growth rate has fluctuated. Figures (3A.6) and (3A.7) present the changes of 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 to 1982, which aimed at attracting foreign investment through a series of incentives. Although, the economy initially expanded due to that policy, this seems to have been unsustainable and the growth rate has consequently decreased.

Figure (3A.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 (3A.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 to 2010.

Finally, Figure (3A.10) presents the GDP per hour worked (constant at $2000) as a measure of labour productivity for the 1960- 2010 period[59]. 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

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

[59] From a theoretical perspective, there are two opposing impacts of working long hours on labour productivity. The first effect is that working longer hours means producing more and thus leads to greater productivity. The second is that working longer hours lead to fatigue, which may marginalize productivity. The low labour productivity in Egypt can reflect distortions in labour market caused by rising employment of low productivity workers, an increase in the apparent number of working hours without a corresponding increase in production, or general failure in labour utilization.

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 (3A.2) 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 (3A.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 (3A.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 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.

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

The role of population on emissions

The assessment of the population pressures on carbon dioxide emissions is illustrated in column 2 of Table (3A.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 neighborhood of 2 (specifically 2.14), suggesting an absence of serial correlation of error terms. See system residuals estimation in Figure (3A.11).

A significant 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 significant positive 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 significant 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 of 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.

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 (3A.5). This model fits the data well, with an Adjusted R-squared statistic equal to 0.77 and the DW statistic is in the neighborhood of 2 (specifically 2.25). See system residuals estimation in Figure (3A.11).

The results emphasize a positive association between mortality due to outside air pollution and carbon dioxide emissions. An increase of 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.

The impact of health on productivity

The estimation of the third equation is illustrated in column 3 of Table (3A.5), this equation tests the hypothesis that poor health has adverse impact on labour productivity. The variables included in this equation are: poor health, TFP, 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 neighborhood of 2 (specifically 2.2). See system residuals estimation in Figure (3A.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, require novel methodologies based on comprehensive analytical methods in order to analyze 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 deal with the determinants of sustainable development through analyzing the relationship between population and the environment have concentrated on the impact of population growth on the environment, especially air pollution, by adopting a 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 (see Figure 3.1).

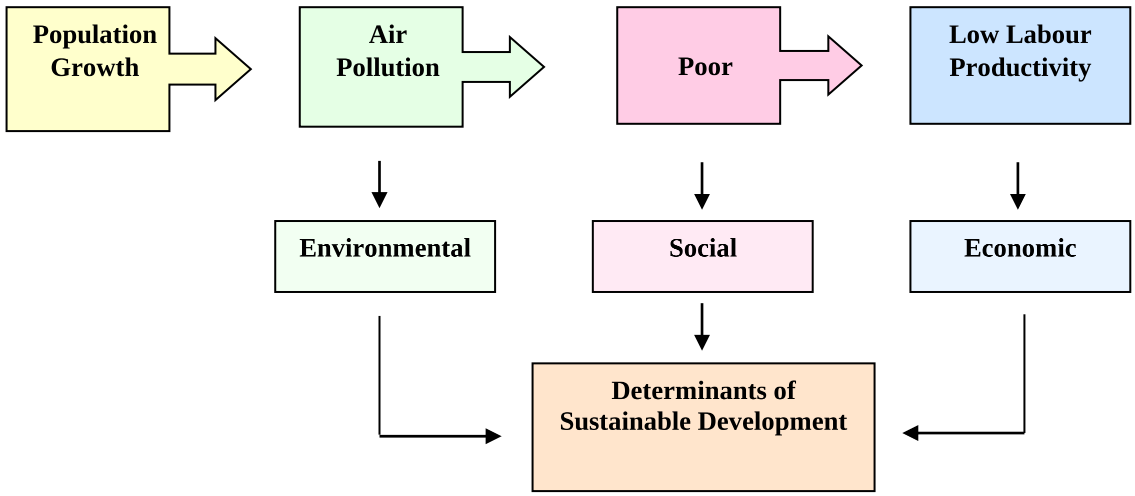


Figure (3.1): Population Growth and Sustainable Development: A Pathway Framework

This argument was followed in developing a 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 policy makers 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[60]. Therefore, policymakers should 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 1960th, 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 cause 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.

[60] 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 to 1.67%.

As illustrated in this study, economic growth[61] 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., 2003), environmental protection in Egypt is troubled by the ineffectiveness of environmental policies and deficiencies in their implementation, 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, 2007). 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, holding all other variable constant, 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 endeavor. 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

[61] 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 known as the *EKC* where the emissions initially get worse but lately improve with income.

Egyptian health sector's response to air pollution threats, planning should be 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 depends 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[62]. 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.

[62] 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. As it was established that population growth plays a significant role on 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 negatively affects labour productivity.

The preceding discussion reveals that the variables which determine the environmental, social, and economic status can also determine the chances for sustainable development of the economy, and that failure to recognize the interdependence among these variables could be a probable reason for the difficulty facing the achievement of economic sustainable development in Egypt. From the evidence available, it can be argued that without adequate theorizing, it couldn't 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.

Chances for Sustainable Economic Development in Egypt

As the preceding discussion clarified, the variables which determine the environmental, social, and economic status can also determine the chances for sustainable development of the economy, and failure to recognize the interdependence among these variables could be a probable reason for the difficulty facing achieving economic sustainable development in Egypt. Therefore, 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.

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.

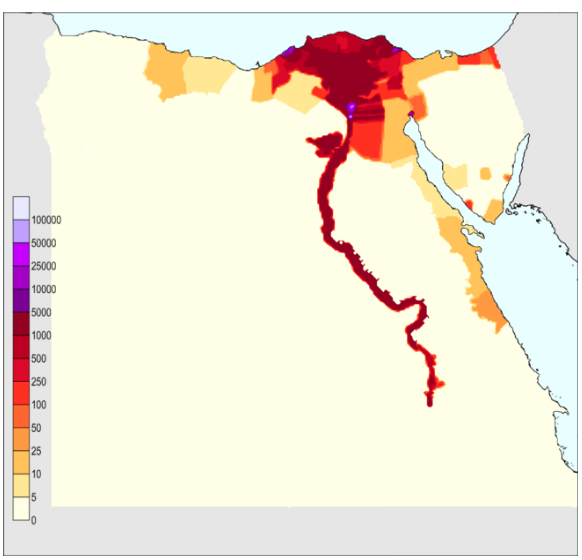
In a wider view, the development and validation of this model should help in achieving a clearer understanding, along with answering many crucial questions concerning the relationship between population and the environment, and its impact on sustainable development. For example, questions about the nature 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.

Appendix (3A): Data and Estimation Results

Figure (3A.1): Map of the Arab Republic of Egypt

Source: EEAA, 1999.

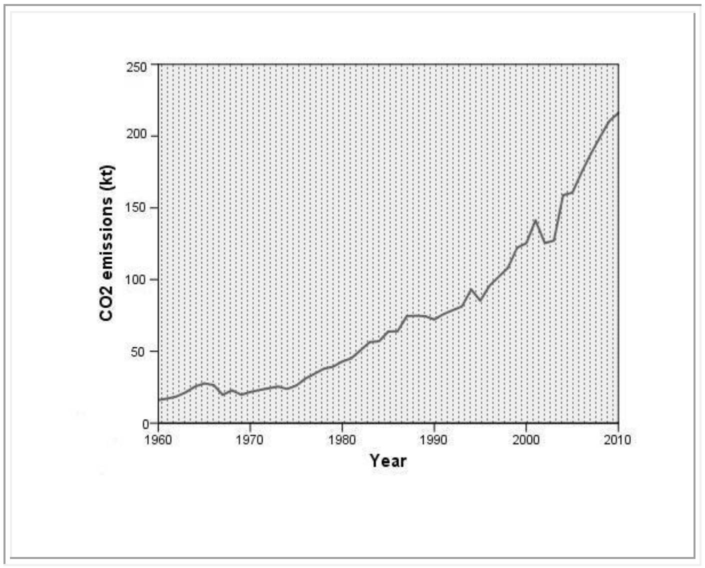
Figure (3A.2): Egyptian Population Density (person per km2)



Source: CAPMAS.

Figure (3A.3): Egyptian Annual Carbon Dioxide Emissions: 1960-2010

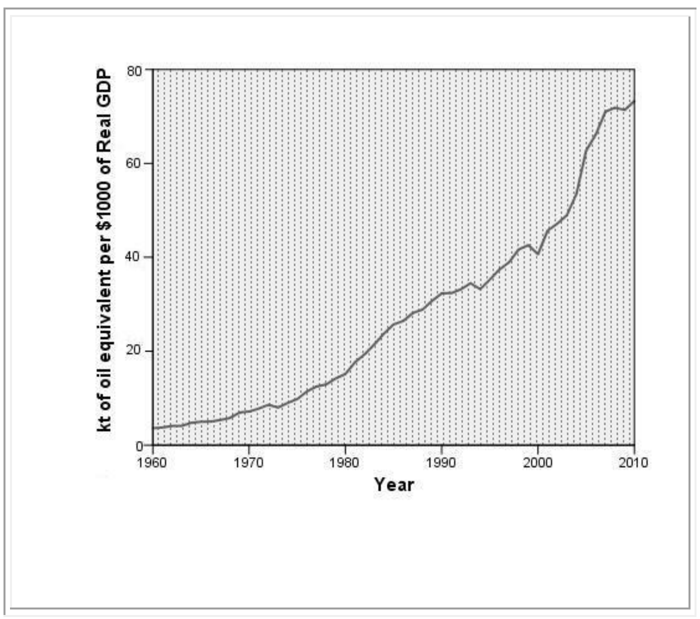
(Thousands)



Source: WDI database.

Figure (3A.4): Kg oil equivalent per $1000 of GDP (constant 2000 US$): 1960-2010

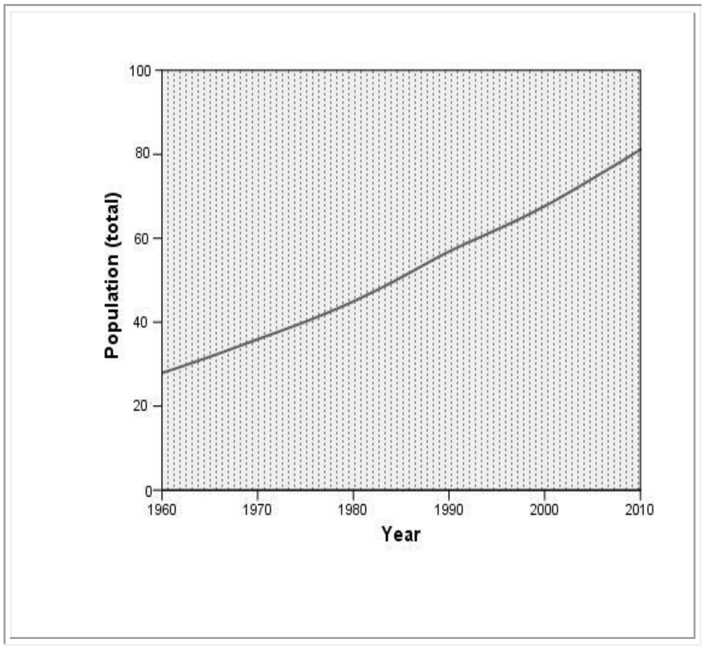
(Thousands)



Source: WDI database.

Figure (3A.5): Egyptian Population: 1960-2010

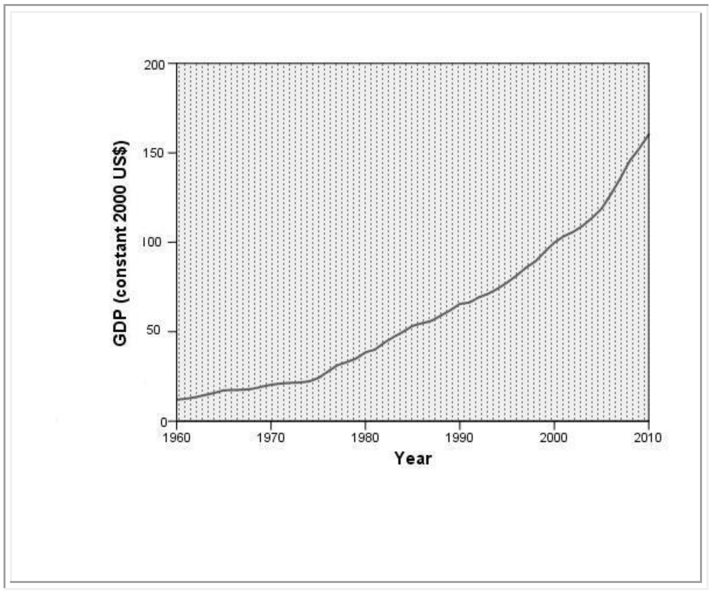
(Millions)



Source: WDI database.

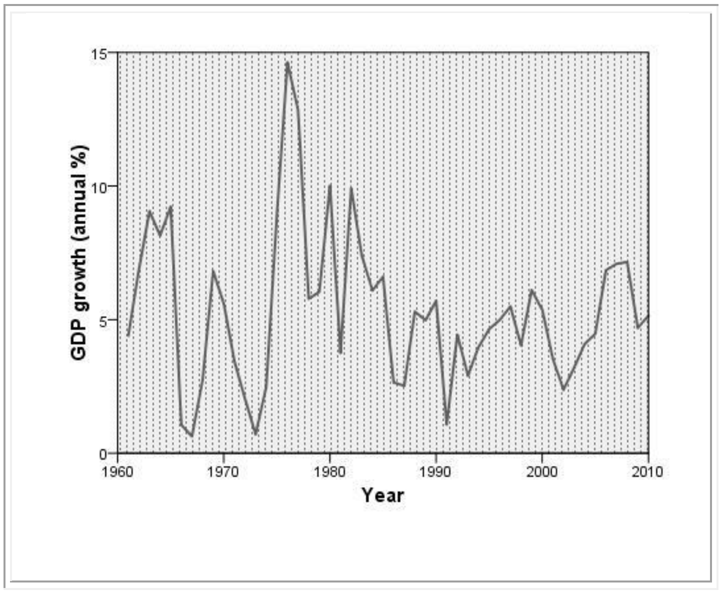
Figure (3A.6): Egyptian GDP (constant 2000 US$): 1960-2010

(Billions)



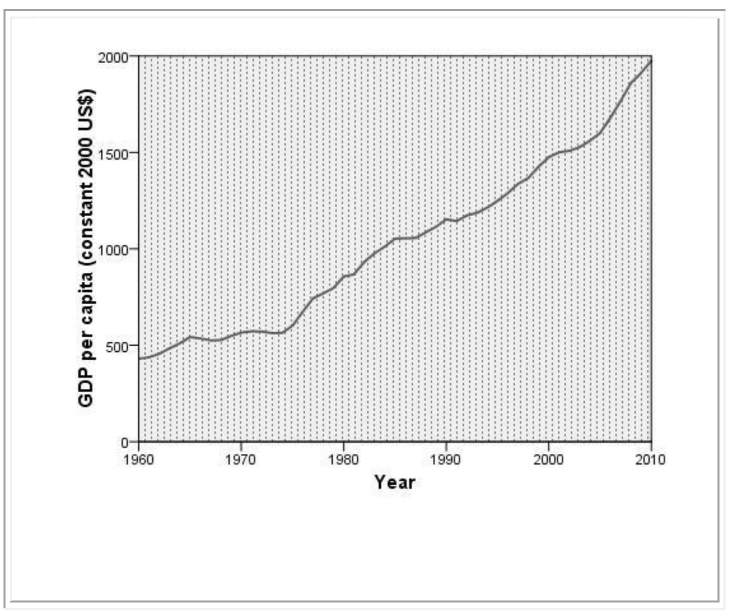
Source: WDI database.

Figure (3A.7): Egyptian Annual GDP Growth Rate: 1960-2010



Source: WDI database.

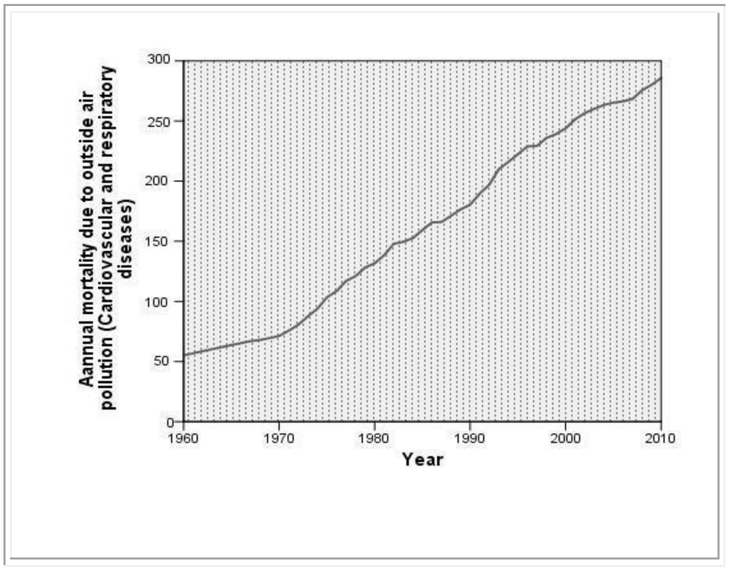
Figure (3A.8): Egyptian GDP per Capita (constant 2000 US$): 1960-2010



Source: WDI database.

Figure (3A.9): Annual Mortality due to Outside Air Pollution (respiratory and cardiovascular diseases): 1960-2010

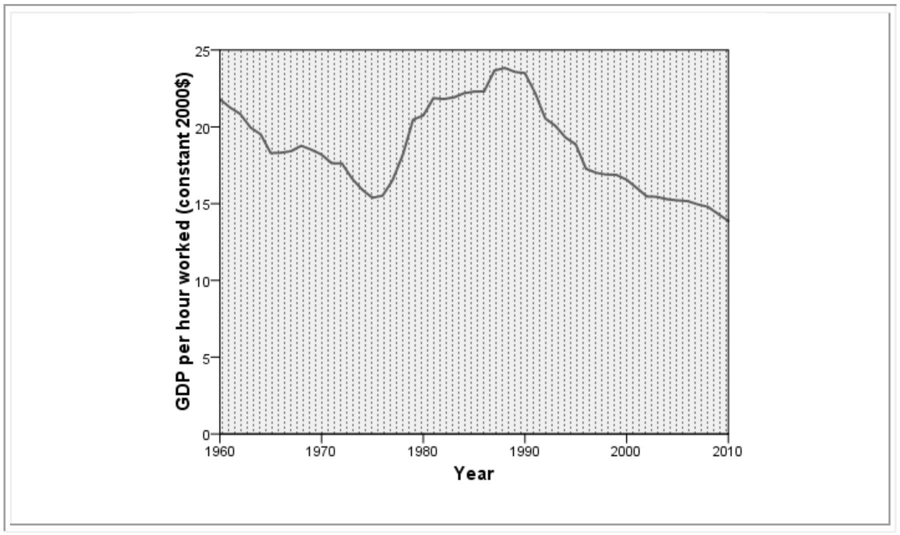
(Thousands)



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 was collected from a Doctoral Thesis about analyzing 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) was 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 data was collected from the NICHP.

Source: (Ahmed, 1990), (Najem, 1975), (NICHP, 1989), (Saied, 2002), and (NICHP database).

Figure (3A.10): GDP per hour worked (constant 2000 US$): 1960-2010



Note: Total hours worked data for the period 1960-1999 is drawn from 5 unpublished labour force surveys made by the ALO, League of Arab States. For the period of 2000- 2010 the data was obtained from the CAPMAS database.

Source: (ALO), and (CAPMAS database).

Table (3A.1): The 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
TFP	Residual of (Coob- Douglas) production function estimation	Number

Table (3A.2): Correlations of Variables Used in Equation No.5: 1960-2010

Variable	(1)	(2)	(3)	Mean	Std. dev	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 (3A.3): Correlations of Variables Used in Equation No.6: 1960-2010

Variable	(1)	(2)	(3)	Mean	Std. dev	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	19755.55
(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 (3A. 4): Correlations of Variables Used in Equation No.7: 1960-2010

Variable	(1)	(2)	(3)	Mean	Std. dev	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) TFP.
(4) Education index.

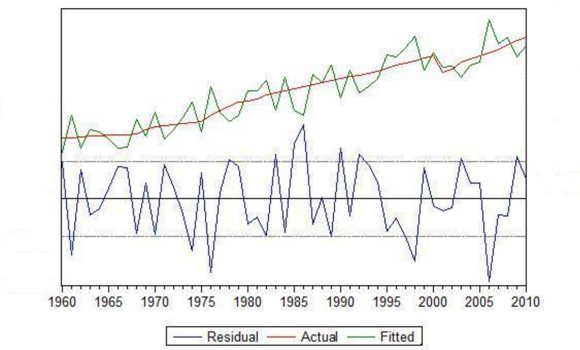
Table (3A.5): Unstandardized Coefficients from the Regressions of the Recursive System of Equations: 1960-2010

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**
TFP	…..	…..	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			

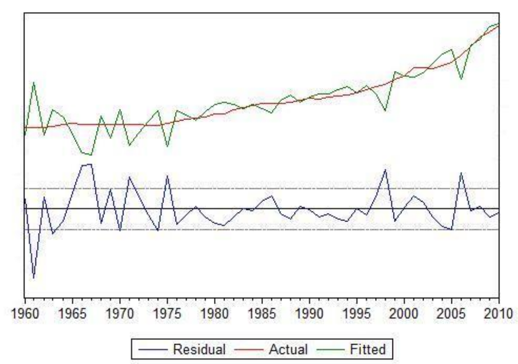
All variables are in logarithmic forms except both the activation of environmental laws (dummy variable) and TFP series (has negative numbers).
The error terms are adjusted using Maximum Likelihood Methods.
***P < 0.01, **P < 0.05, *P < 0.10

Figure (3A.11): System Residuals Estimation

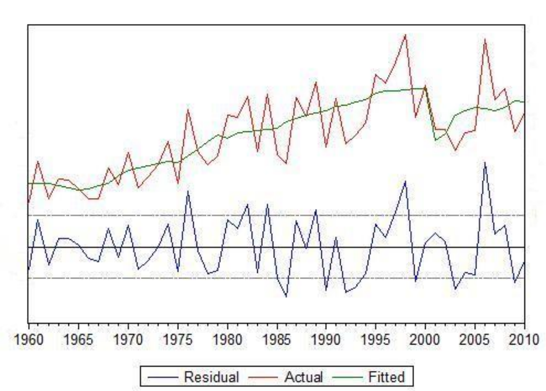
Residuals of the First Equation. Dependent variable: Log (CO_2 Emissions)



Residuals of the Second Equation. Dependent variable: Log (Mortality due to outside air pollution)



Residuals of the Third Equation. Dependent variable: Log (Real GDP per hour worked)



Part II
The Economic Value of Environmental Quality and Health Risk Reduction

Chapter 4

The Economic value of Environmental Quality and Health

1. Introduction

The economic value as a concept has its foundations in the neoclassical welfare economics. According to the theory of economic value, the value of any good or service depends on its ability to satisfy human needs and to increase the utility or welfare of individuals (Hanemann, 1984; Hanemann and Brandt, 2006). Corresponding to this view, the economic value of environmental quality[63] can be measured by its contribution to human well-being (Ehimke and Shogren, 2008). The economic value of an improvement in this quality, such as clean air, can be inferred by observing or predicting the changes in individual's utility or welfare associated with such improvement (Bergstrom, 1990). In this theory, each individual, given his/her fixed income, has well-defined preferences among different combinations or bundles of goods. These bundles include several quantities of market goods and non-market commodities, such as those provided by the environment, in addition to the qualities of these environmental goods and services. Because individuals are assumed to know their preferences, therefore these preferences have a property of substitutability among the market and non-market goods included in the bundles. The assumption of substitutability plays a central role in measuring the economic values of non-market goods, through either predicting individuals' behavior towards environmental goods and services or observing it in real world settings (Hanemann and Brandt, 2006). Also, according to this theory, people are assumed to behave rationally, thus in any given situation they would make the choices that result in their optimal level of benefit or utility. A special application of the economic theory of value within ecological economics is the valuation of health benefits, or health risk reductions, resulting from environmental improvements, and the valuation of damages to human health due to environmental degradation (Bolt et al, 2005).

In this chapter we introduce the theoretical framework for valuing environmental quality and health. Section (2) highlights the techniques which have been frequently used in valuing changes in environmental quality and health risks linked to environmental degradation, in addition to the role that such economic valuation can play as a tool in facilitating the formulation of stronger environmental policies. Section (3) discusses in detail the CVM, which is the main focus of this chapter. In this section,

[63] See Appendix 4A for a detailed discussion of the different concepts of the value of ecosystems and the role of valuation in environmental policy decision making.

we present the development of CVM in environmental economics, CVM merits and limitations, credibility and reliability issues, and sources of bias and ways to mitigate them. In addition, we also discuss sampling and survey design techniques, elicitation formats, and some recent CVM empirical literature on the WTP for improved air quality, and the VSL.

2. Methods of valuing changes in environmental quality and health risk

A wide variety of valuation techniques have been devised in order to evaluate the economic value of changes in environmental quality and the associated changes in health risk. These techniques have different assumptions and data requirements depending on the values they aim to capture, also each of these methods has its own advantages and limitations. The selection of the appropriate method depends on the policy being examined, and on the aims and objectives of intervention (Von Stackelberg & Hammitt 2009). The main methodological approaches[64] can be classified into three main categories[65]. The first category includes methods that depend on measuring an impact, such as the *Dose-Response Functions, Quality Adjusted Life Years,* and *Human Capital*. The second category includes cost-based techniques[66] such as *Cost of Illness,* and *Defensive Expenditure* or *Averting Cost*[67]. Finally, the third category consists of methods based on human behaviour, namely *Revealed Preference* and *Stated Preference*. In this section, we review some of these economic valuation methods which have been frequently used in order to estimate the health and social benefits associated with an improvement in air quality.

2.1. Methods Based on Measuring an Impact

These methods can be divided into two categories. The first one includes methods which aim at valuing changes in health, such as the Dose-Response Functions, and the Quality Adjusted Life Years score (QALYs). The second category includes methods which aim at estimating the value of changes in

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[64] In addition to the Benefit Transfer technique (also called unit value transfer), which is one of the most common valuation methods for environmental quality. In this method, the economic value of environmental quality is estimated by adapting and using economic value information derived from a completed study for a specific location under certain conditions for valuing environmental quality in another location with similar resources and conditions (Chestnut et al., 1997; Rozan, 2004; Von Stackelberg & Hammit, 2009).

[65] Many criteria have been suggested for classifying the wide variety of techniques which have been developed in order to value non-market environmental goods. For example, these methods can be classified based on whether the analytical approach used values the environmental change directly, as in the CVM, or indirectly as in the Hedonic Property Method. Also, they can be classified based on the nature of the market used to value the environmental good, and on whether it is a conventional market, as in the Defensive Expenditure Approach, an implicit market, as in the Hedonic Wage method, or a constructed market as in the CVM.

[66] Cost-based techniques include several other methods such as replacement and relocation costs and opportunity cost analysis.

[67] The Averting cost method can also be classified as one of the Revealed Preference approaches.

production such as the Human Capital approach, which is used for valuing productivity loss due to environmental degradation.

A. Dose-Response Functions

A great body of literature on the economic valuation of changes in environmental quality and their associated health risks relies on dose-response functions (sometimes also called exposure-response relationships), and on damage function techniques. These methods are based on identifying a link or a biological relationship between a particular change in environmental quality (e.g. pollution level), and the level of some economic activity (e.g. agricultural crops or building materials) or some consumer utility (e.g. health damage), where this relationship plays a significant role in the monetary valuation of environmental improvement (Von Stackelberg & Hammitt 2009).

Krupnick et al (1996), for example, have estimated the impact of three air pollutants, namely PM, SO_2, and lead (Pb), on human health, in order to evaluate the benefits of air pollution control in Central and Eastern Europe (CEE)[68]. Their model links ambient air quality standards to physical impacts on health and assigns monetary values for these impacts. Miranda et al (2016), have also used the does-response approach in order to evaluate the health impact associated with the implementation of four different abatement procedures for reducing PM_{10} and NO_x air pollutants in Portugal. Hou et al (2016) have utilized exposure-response relationships of PM_{10} levels which were linked with some health outcomes such as chronic bronchitis, asthma, and hospital admission rate for respiratory diseases, between 2008 and 2012, in order to evaluate pollution control policies in Beijing, China. Kowalski et al (2016), have estimated the health benefits of reducing exposure to PM (PM_{10} and $PM_{2.5}$) air pollution such as to assess possible regulatory changes of air pollution standards in Poland. Their main focus was on total mortality and both cardio and respiratory hospitalization rates. Their estimates indicated that people who are more than 30 years old would gain an additional 4.8 months of life as a result of reducing long-term exposure to $PM_{2.5}$ by 5 $\mu g/m^3$, and that 62.8% of hospitalizations due to respiratory and cardiac diseases could be avoided if PM_{10} levels were lowered to 20 $\mu g/m^3$.

B. Quality Adjusted Life Years Approach

In environmental economic literature, the QALYs is a measure used in order to value reductions in health risks gained from air pollution abatement (Kenkel, 2006). It captures both the qualitative and quantitative

[68] Bulgaria, Hungary, Poland, and the Ukraine.

aspects of life. The QALYs score ranges from 0, which indicates death, to 1, which refers to perfect health, for individuals having the same health status (Wagstaff, 1991). Hubbel (2006) has employed the QALYs approach in conducting a cost-effectiveness analysis for air pollution regulations, where the QALYs have been used as a measure of effectiveness. Schmitt (2016) also has evaluated the public health benefits of controlling air pollution using QALYs in the UK. The study focused on the cardio-respiratory (namely chronic obstructive pulmonary disease, coronary heart disease and lung cancer) effects of long-term exposure to $PM_{2.5}$ air pollution. The findings indicated that there are significant QALYs gains from air quality improvement, as reducing the mean concentrations of $PM_{2.5}$ by 1 $\mu g/m^3$ is expected to yield approximately 63,000 QALYs in London alone, and about 540,000 QALYs in all of England and Wales, for people aged 40 and above over their remaining lifetimes. The expected discounted monetary gains of pollution control intervention, at a discount rate of 3.5% per annum, amount for £4 billion in London and for £34 billion in all of England and Wales.

Hammit (2002) has used a measure similar to QALYs in valuing gains from regulating air pollution, namely the DALYs. The main difference between these two measures is that QALYs measure the value of an ideal health condition relative to the current health status, while DALYs include weighting factors such as age, and thus it measures the loss of health and longevity relative to a perfect or an ideal health status.

C. Human Capital Approach

Many studies have employed Human Capital Surveys in order to value the output of environmental policies through estimating the productivity loss due to pollution-induced illnesses measured in sick absence days. Kosonen and Tan (2004) have examined the impact of indoor air quality on productivity loss. Their findings indicated that poor indoor air quality could result in a significant productivity loss ranging between 5% and 9%, and that improving indoor air quality in workplaces can reduce productivity loss by about 0.5–2%. Neidell (2017) has explored the effect of both ambient and indoor air pollution, represented by $PM_{2.5}$ and Ozone, on labour productivity in agriculture, manufacturing, and the service sectors. His findings suggest that strengthening air quality policies and measurements can lead to greater productivity gains in developed countries, where air quality policies are well-enforced, compared with the developing countries, where environmental regulations are ineffective and air quality policies and measurements are limited, and where environmental quality is often sacrificed for the sake of economic growth.

2.2. Cost-Based Techniques

When valuing an environmental change using cost-based methods, we usually distinguish between methods which estimate the additional costs experienced after an impact has occurred, such as the Cost of Illness approach, and methods which estimate the additional costs that individuals spend in order to avoid the risk of an adverse impact, such as the Averting Cost method.

A. Cost of Illness

The cost of illness (COI) method has been widely used in environmental economics literature in order to value the changes in health associated with an environmental change. This method estimates the change in costs brought about by a change in the incidence of a particular environment-related disease. According to this approach, health expenditures or medical expenses such as the cost of doctor visits and the cost of treatment are considered to be the direct cost of illness. Meanwhile, loss of wages due to sickness and premature death, and the value of the lost products of labour, both denote the indirect cost of illness (Bolt et al, 2005). The value of health risk reduction corresponding to an improved environmental quality can be measured by the sum of the reductions in both the direct and indirect costs associated with a disease (Tolley and Babcock, 1986; Alberini and Krupnick, 2000).

Using the COI approach in conducting benefit-cost analysis for assessing pollution control projects has been the subject of much debate because the indirect costs are difficult to measure, especially for informal workers and for retirees. However, this method can still provide useful guidance in navigating the cost of health degradation or damages attributable to some particular environment-related disease. Alberini and Krupnick (2000) have compared COI estimates and the WTP estimates of the health damages resulting from minor respiratory symptoms associated with air pollution, and found that the COI estimates are lower than the WTP, in consistency with economic theory. Also, Simons et al (2016) have estimated the cost that can be saved annually in medication purchases (daily sales of asthma and chronic obstructive pulmonary disease medicines) corresponding to a 10% reduction in NO_2 and PM (PM_{10} and $PM_{2.5}$) air pollution levels in Belgium. They found that there is a significant association between prescription medication purchases and NO_2 levels, and that reducing NO_2 levels by 10% would result in an annual cost savings of 1.2 million Euros.

B. Averting Behaviour

Averting costs or defensive expenditures are the sum of the preventive expenses that a person is willing to spend in order to avoid the risk of an adverse impact. According to economic theory, a rational individual is willing to spend an amount of money on the activities that reduce the health risk associated with air pollution until the point where the marginal defensive expenditures would equal the marginal value of health risk reduction. Gubta (2006) has estimated the monetary value of health damages that can be avoided as a result of reducing air pollution in the city of Kanpur in India. That study considered both the direct health cost, in terms of wage loss due to sick absence, and the expenditures incurred due to mitigating activities. The findings indicated an annual benefit of 213 million Rupees for the entire population in the city if air pollution has been reduced to a safe level. Janke (2014) has used the avoidance behaviour method in estimating the relationship between children's daily hospital emergency admissions for respiratory diseases and the level of both NO_x and Ozone air pollutants for a panel dataset of UK citizens. The findings emphasized that a 1% increase in the concentrations of either NO_x or ozone increases hospital admissions by about 0.1%.

2.3. Methods Based on Human Behaviour

These methods can be divided into Revealed Preference approaches, where the economic value of a change in the environment can be inferred from individuals' behavioral reaction to this environmental change, and Stated Preference approaches, where the economic value of an environmental change is driven from individuals' choices in a hypothetical market.

A. Revealed Preferences Methods

In Revealed Preference methods, measuring the economic value of a change in the environment is based on observing individuals' behaviour in real-world settings, where this behaviour reflects utility maximization subject to constraints (Hammitt, 2008). Because the change in the quantity or the quality of environmental resources can affect the choices that an individual makes regarding market goods, the value of this change can be deduced through modeling the relationship between market goods and these environmental resources. In these models there is some sort of substitutability or complementarity between environmental services and market goods and services (Ehimke & Shogren 2008). The travel cost method[69] (Poor and Smith, 2004), hedonic property value analysis (Tyrvainen, 1997; Chay and Greenstone, 2005; Van Slembrouck & Van Huylenbroeck 2005; Koundouri & Kougea, 2011), and

[69] Both the travel cost and hedonic prices methods are commonly used to estimate the demand for environmental quality. The travel cost method depends on a surrogate market approach, where information on time and travel costs is used to derive the demand curve for some recreational sites. Meanwhile, the common application of the hedonic pricing technique is in the housing market. This method assumes that air pollution, as an example of environmental degradation, has a direct effect on the value of properties, and that when making housing choices, individuals evaluate a vector of attributes which includes environmental factors such as air pollution. Accordingly, individuals' choices will be reflected in the housing market, and the prices of properties in areas with severe air pollution will be significantly lower than properties located in areas of high air quality.

hedonic wage models (Viscusi and Aldy, 2003[70]; Freeman et al., 2014) are good examples of the revealed preference methodology.

The hedonic wage technique has been widely employed in order to value health risks using the revealed preference method. This technique is based on the idea of compensating the wage differentials received by the workers for doing more risky jobs (Freeman et al., 2014). Accordingly, every job has several attributes including, among others, the risk of accidental death. In the hedonic wage equation, labourers are willing to accept different wage levels as a compensation for different risk levels, and on the other hand, firms are willing to offer workers different wage premiums in order to make them accept the different risk levels, and market equilibrium is obtained when wage offers match wage acceptances. In this case, the value of health risk is represented by the hedonic wage, which describes the compensation received for bearing risk (Simon et al., 1999; Bayer et al., 2009; Hunt, 2011)

B. Stated Preferences Methods

Stated Preferences techniques are the most comprehensive and commonly used methods in estimating the economic value of environmental quality. In these techniques, the economic value is driven from individuals' choices in a hypothetical market, rather than from observing choices in the real world (Tolley and Babcock, 1986; Foster et al., 1997; Mathis et al., 2003; Bosworth et al., 2006, Whitehead and Blomquist, 2006; Atkinson and Mourato, 2008). According to that, individuals can be asked directly about the values they place on some specific change in environmental quality in the context of an imaginary situation (Hammitt, 2008). Popular forms of stated preferences techniques used for electing individuals' preferences are[71]: the CVM (Kriström, 1990, 1997; Hanemann, 1994; Alberini et al., 1997a,b; Carson, 2000; Venkatachalam, 2004; Wang & Mullahy, 2006; Wang & Zhang, 2009; Hausman, 2012; Akhtar et al., 2017), Choice Experiments (Hanley et al., 1998; Carlsson and Martinsson, 2001; Von Stackelberg and Hammitt, 2009), Contingent Ranking (Bateman et al., 2005), and Conjoint Analysis (Halvorsen, 1996; Roe et al., 1996).

Stated preference techniques have often been used in order to estimate the economic value of health as well, which provide policy makers with some insights into how individuals may trade off income with reductions in the risk of some particular effect on health (Ortiz et al, 2009; Hoffmann et al 2012; Hunt et

[70] This work presents a substantial literature review on the VSL, or the trade-offs between money and mortality risks. It reviews more than 60 studies of mortality risk premiums from ten countries and approximately 40 studies that present estimates of injury risk premiums. The results suggested an income elasticity of the VSL ranging between about 0.5 and 0.6. This paper also presents a detailed discussion of policy implications of these VSL estimates and how they can provide governments with a reference point for the benefits to society resulting from mortality risk reductions.

[71] A less frequently used form of stated preferences techniques, especially in studies of health risk valuation, is the Contingent Behaviour.

al., 2016). For example, Hammitt and Graham (1999), Hammitt (2000), Corso et al (2001), Hammitt and Liu (2003), Alberini, (2005), Alberini et al (2006), Alberini and Ščasný (2011), and Mahmud (2019) have employed the stated preference method in order to value risk reductions related to mortality, and to estimate the VSL[72] or the marginal rate of substitution between mortality risk and income, while Dickie and Gerking, (1991a), EPA (2000), Chilton et al (2004), Houtven et al (2008), Hammitt and Haninger (2010), Wang et al (2015), and Ligus (2018) have used it in order to value pollution-induced morbidity.

The CVM is the most frequently used technique, among the stated preference techniques, for valuing health and mortality risk reductions associated with improving environmental quality. In the next section we discuss CVM in more detail.

3. Contingent Valuation Method (CVM)

CVM is a survey-based technique, in which a survey questionnaire is employed in order to create a hypothetical market for a nonmarket good or service (Mitchell and Carson, 1989). In CVM, the economic value of a change in the environment can be estimated using either one of two welfare measures[73]. The first is the WTP, or the maximum sum of money that an individual would be willing to pay for an increase in environmental quality, or for a reduction in the pollution level. The second measure is the willingness to accept (WTA), or the minimum sum of money that an individual would require in order to voluntarily forgo an improvement in the quality of the environment (or to accept a deterioration in environmental quality) (Hoffman and Spitzer, 1993; Ito and Zhang, 2016).

The development of CVM in environmental economics can be traced back to 1947 when Ciriacy-Wantrup first suggested to directly ask consumers about how much they would pay for a marginal increase in the quality of environmental resources, in the context of assessing the benefits of preventing soil erosion (Mathis et al., 2003). The first actual implementation of surveys in environmental economics literature started with Davis (1963) who used an interview method in order to explore the WTP for recreational services. In the subsequent years, CVM started to become widely used in order to value the benefits to society resulting from environmental improvements, such as reducing air pollution (e.g. Ridker, 1967)[74]. The economic framework for valuing pollution-induced health risks was developed by Schelling in

[72] The empirical estimate of the VSL can be derived using either the revealed preference or stated preference methods. In the revealed preference method, the estimate is based on observing individuals' behaviour regarding the trade-off between mortality risk and income (e.g. wage differential). On the other hand, in the stated preference method respondents are asked about hypothetical choices.

[73] See Hausmann (2012) for a more detailed discussion of the differences between the WTP and the WTA.

[74] Although the main focus of this work was on valuing air quality using the hedonic prices method, the author was the first to recognize that individuals may value air pollution and thus have included some WTP questions in the surveys, which were conducted in 1965.

1968[75], in the context of evaluating environmental regulations. Subsequently, the valuable contribution of Mishan (1971), and Acton (1973) to the environment and health economics literature constituted the corner stone for studies on valuing mortality and morbidity risk, and have inspired further investigations.

3.1. Merits and limitations of CVM

The merits and limitations of CVM are well recognized in literature. Mitchell and Carson (1989), Wedgwood and Sansom (2003), Carson and Hanemann (2005), Hanemann and Brandt (2006), Pearce et al (2006), Hausmann (2012), Renda et al (2013), and McFadden and Train (2017) emphasized that with respect to decision making processes, CVM has many advantages over the other approaches, as they can help decision makers to identify the public's interests. For example, the revealed preference method assumes that people are totally aware of the costs associated with environmental degradation and are also aware of the benefits of improving environmental quality, and that they are able to modify their behaviour accordingly, in ways that reveal their preferences. Meanwhile, impact assessment methods, such as dose-response functions, do play an essential role in environmental risk management, but they do not take consumer preferences into consideration. Therefore, CVM as a technique for evaluating the monetary value of the non-marketable consequences of environmental regulatory policies has gained a great acceptance by policy makers. Moreover, the information provided by CVM can guide cost-recovery for environmental policies, thus insuring the financial sustainability of pollution control projects.

On the other hand, Diamond and Hausman (1994), Foster et al (1997), Von Stackelberg and Hammitt (2009), Andersson and Treich (2011), and Hausmann (2012) pointed out that the major drawback of CVM is that it is based on hypothetical choices, which makes it subject to some bias. Hypothetical bias has often been reported in CVM studies, and it is linked to the respondents' lack of understanding of the hypothetical scenario, due to their unfamiliarity with the good being valued, or uncertainty about their preferences (Mitchell & Carson, 1989; Bateman & Turner, 1993; Carson et al., 2001; Wedgwood & Sansom, 2003; Foster & Burrows, 2017[76]; Ferrini & Turner, 2018[77]). In these works, many methods[78] have been suggested in order to mitigate the hypothetical bias or the divergence between the real and hypothetical payments. One method, among others, is to include some follow-up questions about preference certainty, and then restrict the sample to those who are certain about their answers. Also, in

[75] In his article "The Life You Save May Be Your Own".

[76] See McFadden and Train (2017), Chapter 10.

[77] In this paper, Ferrini and Turner discuss the limits and challenges of stated preference methods (for both CVM and choice experiments technique), introduced by McFadden and Train (2017).

[78] Many studies have examined the impact of cheap talk on eliminating the hypothetical bias (e.g Aadland et al., 2005; Brown et al., 2003; Cherry and Whitehead, 2004; Murphy et al., 2003). They concluded that cheap talk is effective in reducing hypothetical bias. However, its effectiveness depends upon the bid level.

order to receive answers which reflect the respondents' true preferences, the hypothetical scenario should be familiar to them and the description of the options must be very clear, along with pre-testing their level of understanding of the surveys.

Another source of bias that is linked to the lack of understanding is the information bias, which is very similar to the hypothetical bias, and depends on both the amount and quality of information offered to the respondents. For example, empirical evidence from CVM studies on the valuation of health risk reduction indicates that the difficulty in understanding small changes of probability by the respondents is problematic and require careful handling (Pearce & Moran, 1994; Hammitt & Graham, 1999; Wedgwood & Sansom 2003). Also, studies which have examined the problem of insensitivity to scale in empirical CVM studies have concluded that offering proper (correct and complete) information to the respondents about the hypothetical change can reduce the likelihood of inappropriate (ignorant or flippant) answers (Bateman & Brouwer, 2005). Also, an important source of bias in CVM surveys is strategic behaviour, which occurs when the respondents have little incentives to truthfully state their preferences, and therefore they may either overstate or understate their WTP. Criticisms of CVM stress both the warm glow effect[79] and free-riding behaviour as possible causes of bias in WTP estimates for public goods (Hackl & Pruckner, 2005).

Biases due to design in CVM studies include non-response bias, which is mainly associated with using open-ended elicitation formats (Foster et al., 1997), in addition to starting point and range biases (Veronesi et al., 2011), interview and sample selection bias, and question order bias. Furthermore, the payment vehicle suggested in the WTP questions may induce a bias in the responses, and that is usually referred to as payment method bias. In order to minimize this bias, the respondents should be familiar with the payment method offered, and this payment vehicle should be as realistic as possible (Wedgwood & Sansom, 2003). Rolfe et al (2002), Stewart et al (2002), and Mathis et al (2003) argued that most of these survey biases can be mitigated by employing a proper survey design. Therefore, it can be said that under the right conditions, accurate estimates of the value of an environmental improvement can be obtained from the CVM surveys.

[79] The warm glow effect is responsible for the occurrence of an embedding effect (insensitivity to scope) bias, which refers to the tendency of WTP responses to be highly similar across different surveys (Hanemann, 1994).

3.2. WTP elicitation Methods

Different WTP values can be generated depending on the elicitation format used (Boyle, 1990). The most popular elicitation formats are: *Open-Ended, Closed-Ended, Bidding Games, and Payment Cards*[80]. In the *open-ended* type of questions, respondents are asked directly about the value they place on environmental improvement, e.g. how much they are willing to pay for the change in environmental quality from q^0 to q^1? Although this method is conceptually simple, because it provides a direct estimate of the WTP, it is susceptible to certain biases, especially non-responses bias (Mathis et al., 2003; Wedgwood & Sansom, 2003).

The second type of questions is the *closed-ended* format, where the respondents are asked to choose from a discrete set of responses, such as between "yes or no", or selecting one or more among a multiple-choice list. This approach allows truthful WTP responses and is considered an incentive-compatible format (Carson & Groves, 2007). The main advantage of this approach is that it avoids many of the biases known to be inherent in the open-ended election format. For example, this election format is more straightforward, and thus tends to generate higher response rates, and therefore it can eliminate the impact of "protest responses" where the respondents give either extremely high or low (zero) responses (Cameron & Quiggin, 1994). In addition, the respondents are usually more familiar with the closed-ended format as it is similar to market transactions, where the consumer is offered a specific price for a good and then decides whether or not to purchase it. Carson and Groves (2007) indicated that the WTP values obtained from dichotomous choices are generally larger than those obtained from open-ended questions due to the large portion of zero responses. Closed-ended questions can be presented in two formats, the first is the *single-bound* discrete choice, where the respondents are asked to agree or disagree to pay a certain amount of money for an environmental change, e.g. would you vote to support the change from q^0 to q^1 if it would cost you $\$A$? In this format, respondents are offered a range of predetermined bid values in which each respondent is presented with a randomly selected single bid. When using this format, responses do not reveal the exact value of the WTP, but they rather provide an interval in which the WTP must lay.

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[80] In the payment card format, respondents are offered values within a reasonable range they would be expected to accept. Meanwhile, in the referendum format, respondents are asked whether they would vote for a government policy, given that it would cost them a certain amount. Bidding games are an extension of the referendum format (Mathis et al., 2003).

The second format is the *double-bounded* dichotomous choice[81], where the respondents are asked two closed-ended questions, with the bid amount in the second question conditional on the response to the first question. For example, "Would you vote to support the change from q^0 to q^1 if it would cost you \$*A*?", If the respondent answered "yes" to the first valuation question, the question is then to be repeated with a higher value $\$A^u$, if the respondent answered "no", then the question is repeated with a lower value $\$A^d$. In this case, because each respondent is being asked two questions, there are four possible outcomes: the answer for both questions could be "yes", the answer for both questions could be "no", the answer for the first question is "yes" followed by a "no" for the second question, and the answer for the first question is "no" followed by a "yes" for the second question.

The main advantage of the double-bounded approach[82] is that it has the potential to generate both an upper and a lower bound on the respondent's WTP (Hanemann, 1984; Carson et al., 1990; Hanemann et al., 1991; McConnell, 1997; Aikoha et al., 2018; Shaha et al., 2018), also it can yield more precise welfare estimates, in addition to overcoming some of the response problems associated with other value elicitation formats[83]. However, McLeod and Bergland (1999) and Von Stackelberg and Hammitt (2009), noticed that in some cases, the responses to the follow-up bid are inconsistent with the responses to the initial bid. Meanwhile, in some other cases the responses to the second bid have been found to be influenced by the first bid proposed. This is commonly referred to as starting-point bias. Cameron and Quiggin (1994), Alberini (1995a,b), and Brouwer et al (2008) emphasized that although the estimated coefficients obtained under the the double-bounded dichotomous choice are sometimes subject to bias, the gain in efficiency is still substantial.

3.3. Credibility and Reliability Issues in CVM

Ever since the National Oceanic and Atmospheric Administration (NOAA) assigned a panel[84] in order to evaluate the methodology of CVM and investigate doubts regarding the estimation of non-use values,

[81] This elicitation format is subject to both anchoring bias, where the respondents anchor their WTP in the initial bid, and shift effects where the respondents perceive the first bid as the true cost of the government policy, and the second bid may be thought of as an additional charges by the respondents who answered 'yes' to the first bid. Meanwhile, for those who answered 'no' to the first bid, it may be regarded as an indication of a lower level of environmental quality (Whitehead, 2002).

[82]Although it leads to a substantial increase in the statistical power of the WTP estimate, that sometimes comes at the expense of a downward bias in the estimate because the second response is not always incentive-compatible (Carson et al., 2001).

[83] Kriström (1997), noted that the "no-no" respondents are composed of two groups, those who really have a zero WTP, and those who have a positive WTP that is less than $\$A^d$, so he suggested a spike model, where a third follow-up question is to be presented to people who gave a "no-no" response, that is "Are you willing to pay anything at all?", and those who answer `no' to this question would then provide a valid representation of a zero WTP.

[84] The NOAA panel (sometimes referred to as the Arrow-Solow panel) was hired in response to the Exxon Valdez oil spill disaster in 1989 in order to evaluate the validity of CVM in valuing non-use values. The panel issued a report in 1993 containing guidelines to conducting CVM studies such as to produce reliable information on environmental damage assessment (Arrow et al., 1993).

many works in literature have focused on credibility, reliability and validity issues within the CVM framework (e.g. Diamond & Hausman, 1994; Hanemann, 1994; Hanemann and Kanninen, 1996; Smith and Osborne, 1996; Carson, 2012; Foster et al., 1997; Klose, 1999; Mathis et al., 2003; Venkatachalam, 2004; Von Stackelberg & Hammitt, 2009; Rakotonarivo et al., 2016). In this context, credibility indicates whether the respondents are answering the main question that the survey is trying to ask, and reliability indicates the size and direction of biases that may occur in the responses. Finally, the validity of CVM refers to both the theoretical validity of the responses, based upon their consistency with economic theory, and to the validity of the survey contents.

The recommendations suggested by the NOAA panel for conducting reliable CVM surveys can be split into general guidelines and survey design guidelines (Carson, 2012; Johnston et al., 2017). Regarding the survey design, both the NOAA panel and the empirical literature on CVM have recommended many procedures which can help improve the quality of survey results through ensuring that the respondents fully understand the questions, that they truthfully express their WTP, and that the non-response rate is minimal. These recommendations include using dichotomous choice and in-person interviews, and the importance of choosing a proper payment vehicle. They also indicated the importance of ensuring that the bid amounts assigned to the respondents in the survey should cover a reasonable portion of the range of possible WTP values. Therefore, care should be taken to avoid bid values that are either implausibly small or large, as the responses to the WTP questions for such amounts might reflect a loss of credibility of the scenario, rather than the true respondents' preferences.

Also, the recommendations include the importance of pre-testing using pilot surveys and focus groups, and including a clear definition of the population, the sampling frame, and the sample size in the study. Furthermore, all data from the study should be archived and made available to interested parties. Additional recommendations included using the WTP instead of the WTA. Also, that an accurate description of the program or policy in question (hypothetical scenario) must be provided to the respondents in order to enhance realism and encourage them to answer honestly, and that some follow up questions should be asked in order to determine the reason that the respondents have elected to vote in support or against the policy being evaluated. Demographic information and other characteristics such as prior knowledge of environmental issues, attitudes toward the environment, understanding and belief in the scenarios should be collected, and their relationship with the WTP should be reported. It is also recommended to remind the respondents that their positive WTP for the environmental improvement project in question can reduce their expenditure for other private and public goods. In addition, it is recommended to include an inquiry at the end of the survey in order to explore the effectiveness of the survey, or to ensure that the respondents have understood the information and the credibility of the scenario, and that they took the survey seriously.

3.4. Empirical Evidence

A great body of empirical literature on CVM focuses on its use in measuring the value which people place for environmental quality, through valuing the cost of morbidity and mortality and the benefits of reducing health risks. Bellavance et al (2009) indicted that the WTP is one of the most suitable methods for measuring individuals' preferences in matters of health risk. The list below presents a brief review of some of the empirical literature on measuring the WTP for improving air quality and for reducing the health risks attributable to air pollution, in addition to evidence on the different attributes that have been found to affect the WTP, and consequently the VSL.

Focusing on morbidity attributable to air pollution, Alberini et al (1997b) have conducted a CVM study in order to value air quality in Taiwan by estimating the WTP for avoiding minor respiratory illnesses. They found that the WTP to avoid illness tends to increase with the duration of illness, the number of symptoms experienced, and with educational and income levels. In a study aimed at evaluating the national standards for PM_{10} and $PM_{2.5}$ set by the U.S. Environmental Protection Agency (EPA) in the USA, Ostro and Chestnut (1998) have estimated the annual health benefits of reducing the ambient concentrations of $PM_{2.5}$ to be between US$14 billion and US$55 billion, with a mean estimate of US$32 billion. Navrud (2001) has used CVM in order to estimate the mean WTP for an environmental program that would result in morbidity risk reduction in Norway. Based on in-person interviews of 1009 individuals, he estimated that the mean WTP for the avoidance of 1 and 14 additional days of light health symptoms and asthma to range between 99 NOK and 812 NOK (US$11 and US$93) per year. Desaigues et al (2004) have estimated the annual WTP over the following 10 years in France for a medical treatment that would reduce the risk of dying from air pollution by 1 in 1000 to be €412 (US$ 470), and the WTP for a reduction by 5 in 1000 to be €563 (US$ 645). Dziegielewska and Mendelsohn (2005) have examined the adverse impact of air pollution on health using CVM in Poland, where 1055 persons were interviewed and asked about their WTP for reducing certain health risks. The payment vehicle used is this study was a one-time increase in taxes. They produced WTP estimates for risk reductions of mortality, incidence of bronchitis, asthma, minor health symptoms, and for visibility loss, associated with two air pollution reduction levels (50% and 25%). The results of all these studies reveal that individuals' WTP to reduce health risks vary across different individuals, as people have differing attitudes to risk, also valuations vary with income, the level of risk and the health state to be avoided.

Wang and Mullahy (2006) have conducted a CVM study in order to estimate the economic value of reducing fatal risk through improving air quality in China. In-person interviews have been conducted for 500 respondents in Chongqing, China. The respondents have been offered a series of hypothetical open-ended scenarios in order to elicit their WTP for a reduction in air pollution level. In that study, about 96% of respondents have expressed their WTP, and the VSL has been estimated to be $34,468. Based on the estimated income elasticity, the authors concluded that people in China still consider clean air to be a luxury good. Wang and Zhang (2009) have estimated individuals' WTP for improved air quality in China using CVM. In-person interviews have been conducted for 1500 residents of the city of Ji'nan. The WTP was elicited through open-ended scenario questions, where approximately 60 percent of the respondents have expressed a positive WTP for improving air quality. They have estimated the mean WTP to be ¥100 (US$ 15.5) per person per year. About 40 percent of the respondents had no incentive to bear the cost of improving air quality, where their main reason was believing that improving air quality is a government responsibility. They concluded that the high percentage of protest responses within this sample may reflect the impact of a rather low level of environmental awareness. However, this high rate of protest responses can be traced back to the open-ended question format which has been used in that study.

Greenstone and Hanna (2014) have analysed the effectiveness of two pollution reduction policies in India by using city-level air and infant mortality data to calculate the benefits of these regulations. Their results indicated that air regulations have contributed to improving air quality and to a slight reduction in infant mortality. They also found that individuals' demand for improved air quality have prompted the Indian Supreme Court to take action, thus further contributing to the success. Wang et al (2015) have used CVM to measure the WTP for reducing children's respiratory diseases in Shanghai, China. The sample has been chosen from parents in both the general community (parents who have healthy children) and from hospital settings (Parents who have sick children), holding interviews with both groups. Parents who had sick children were found to be willing to pay significantly more (¥504, or USD$80.7) than parents in the general community sample (¥428, or USD$68.5). In these studies, other important predictors for the WTP were found to be education and income. The results emphasized that the hospital setting may provide a unique opportunity to improve education about air quality and children's health, as the parents may be more receptive to the information.

As mentioned earlier, environmental policies have often been evaluated using the VSL. The VSL for an individual can be obtained by dividing his/her stated WTP for mortality risk reduction by the magnitude of the risk reduction under consideration (Hammitt & Graham, 1999). In theory, the VSL for an individual is the slope of the indifference curve that reflects his/her preferences for wealth and survival probability, which depends on the size of the risk change. Many factors such as environmental quality, health status, and policy interventions affect the mortality risk and the probability of surviving, thus causing shifts in the individuals' survival curve (Hammitt, 2008).

Krupnick et al (2002) have conducted a CVM study in Hamilton city, which is located in the Canadian province of Ontario, for 930 persons aged 40 to 75 years, in order to elicit WTP for a hypothetical intervention that would reduce the individual's risk of dying in the following 10 years by either 1 in 1000 or 5 in 1000. The sample was restricted to individuals aged 40 years and above. They found that the estimated VSL is almost constant for ages between 40 and 69 years old, and that it is smaller for individuals aged 70 and above by about 30 percent. Vassanadumrongdee and Matsuoka (2005) have conducted two surveys in order to estimate the WTP for reducing the mortality risk associated with air pollution in Bangkok, Thailand. Their results indicated that the main factors affecting the WTP for reducing the mortality risk attributable to air pollution are the severity, controllability and personal exposure to air pollution. They estimated the VSL related to air pollution to range between \$0.74 million and \$1.32 million.

Hammitt and Zhou (2006) estimated the health benefits due to improving air quality in three regions in China. Health risks were represented by two morbidity effects (cold and chronic bronchitis) and by mortality. They estimated the mean VSL for two mortality risk reduction levels, 1 in 10,000 and 2 in 10,000, to range between \$15,000 and \$180,000. Also, they estimated the median WTP for preventing an episode of cold to range between US\$3 and US\$6, and the WTP for preventing a statistical case of chronic bronchitis to range between US\$500 and US\$1000. Their results suggested that the WTP tends to be higher for younger, more educated, and higher income respondents. On the other hand, in contrast to theory and to the vast majority of empirical work on risk reduction, their results indicated a lack of scope sensitivity, as they found the variable indicating risk reduction to be not significantly different from zero, which suggests that the magnitude of risk reduction was not an important factor for the respondents within this sample, and may indicate low confidence in these results.

Risk perception plays an important role in valuing mortality risk. Krupnick and Cropper (1992) have found that individuals who have or have had an experience with chronic respiratory diseases (within friends or family), are willing to pay more in order to reduce the risk of these diseases. Dickie et al (2020) have examined the impact of both information about and perceptions of risk of heart diseases on the marginal WTP for risk reduction. Their results indicated that the information on heart diseases and the perceptions of risks which individuals held initially before receiving proper risk information have had a significant impact on the marginal WTP estimates. Also, Hammitt and Liu (2003) compared the WTP for reducing the risk of lung cancer with that for reducing similar chronic lung diseases associated with industrial air pollution, and found that the former is larger than the latter by about one-third.

Many studies have tried to check the validity of the results obtained through CVM by comparing them with other valuation methods. For example, Dickie et al (1987) have compared the CVM and averting behaviour estimates of the WTP for avoiding health symptoms (chest tightness, throat irritation, headache, and pain when taking deep breaths) associated with ozone exposure. Their results indicated that the estimates obtained from the averting behaviour method tend to overestimate the WTP. Dickie and Gerking (1991b) have estimated the WTP for tropospheric ozone control using the demand for medical care. They found that people who are exposed to high levels of ozone are willing to spend about $170 annually in order to reduce ozone concentrations to less than 12 parts per million. The results also indicated that the WTP figures are larger than (by two to four times) the savings in medical expenses resulting from the same ozone reductions. Chestnut et al (1996) compared the WTP for avoiding negative health changes (changes in angina symptoms) due to exposure to air pollution (carbon monoxide) with the COI in the United States. The study targeted heart patients with angina, and found that the estimated mean WTP is similar to the COI estimates.

It is worth mentioning that the main difference between the COI and the WTP measures is that the COI represents the additional costs experienced after a sickness has occurred, while the WTP indicates the value that people place on a change in health risk before the medical condition or the health risk occurs. Thus, the WTP is a measure that captures many values that the COI is not able to capture, such as the monetary value of avoiding pain and suffering resulting from illness, or the financial burden associated with averting behaviour (Cropper, 1981; Landefeld & Sekin, 1982). Therefore, economic theory predicts that the WTP estimates should generally be greater than the COI estimates, and that the latter can be considered as a lower-bound estimate of the WTP. Alberini and Krupnick (2000) also compared the WTP estimates for minor health damages attributable to PM air pollution with the COI estimates. The main objective of that study was to test the validation of the economic theory prediction that the WTP should be greater than the COI. Total COI is estimated by combining both direct expenditures such as doctor visits fees and prescription medication expenses, and indirect expenses, particularly the lost earnings due to sick absence. Their empirical results seem to confirm that the WTP estimates do indeed exceed the COI estimates.

Literature on evaluating environmental policies have given special attention to the role that human health metrics such as QALYs, DALYs, and the WTP for health risk reduction can play as a support tool for environmental decisions (Wagstaff, 1991), and the importance of comparing the monetary values of pollution control obtained by these measures in order to obtain a credible value for environmental quality. For example, Hubbel (2006) has conducted a cost-effectiveness analysis for air pollution regulations using QALYs as a measure of regulation effectiveness. He concluded that if a regulation's impact is mainly on mortality, the QALYs based cost-effectiveness analysis, and the WTP based cost-benefit analysis are then very similar in their conclusions. However, if the regulation's impact on morbidity is more significant, the QALYs and the WTP estimates would yield different evaluations of the efficiency of the regulation.

Many studies have used the compensating wage or hedonic wage approach, which uses market prices in order to value the health risk, and have compared the measured values to the WTP obtained from the stated preference method (Fisher et al., 1989; Simon et al., 1999; Bayer et al., 2009). Hunt (2011) emphasized that although the data required for conducting the hedonic wage approach is more easily obtained, there are many limitations associated with this approach compared to the CVM. In the compensating wage approach, the sample is restricted to a small segment of the population, such as the working age group[85], and the participants tend to reveal an immediate perception of environmental risk. Thus, the hedonic wage method is likely to overstate the valuations of health risk.

In contrast to the CVM, the assessment of averting or mitigating behaviour in response to changes in pollution levels requires the assumption that individuals do know the relationship between some specific pollutant and their health condition, but this is not always true. Roe et al (1996), Bateman et al (2002), and Greenstone and Gayer (2009) have argued that methods such as choice experiments, and conjoint techniques seem to share many of the advantages and disadvantages associated with CVM, and that in the context of environmental valuation all these methods can guide decision makers and lead to more efficient environmental policies that increase social welfare.

3.5 Afterthoughts

The previous review of theoretical and empirical literature on valuing environmental quality and health indicates that a carefully designed CVM study can provide policy makers with valuable insights into the trade-offs that people are willing to make in order to improve environmental quality, or in order to reduce health risk levels. Ignoring these trade-offs can lead to counterproductive results of proposed policies. Furthermore, comparing individuals' WTP for avoiding adverse health impacts of air pollution with the

[85] Or the segment of population which has the financial ability to move to a new house in response to an environmental risk, in case of using the hedonic property prices technique.

costs across policy options, can provide policy makers with a perception of the magnitude of total health benefits related to a particular air regulatory policy or pollution control project (Freeman et al., 2014).

The previous review of empirical CVM work shows that the value that people place for a reduction in their health risks, and hence the corresponding VSL estimates, depend mainly on two groups of factors. The first group pertains to the socio-economic characteristics of the individuals, such as wealth, age, education, and health status. The second group is related to the characteristics of the risk being considered, such as the type of risk, the baseline risk, the background risk, and the magnitude of risk reduction that the respondent have to value. However, the direction of such effects remains to a great extent empirically and theoretically ambiguous (Alberini et al., 1997b). For example, many CVM studies have not found a statistically significant relationship between the VSL and wealth, despite that the VSL is theoretically predicted to increase with income level (Hammitt and Robinson, 2011).

Also, almost all CV studies have included age as an important factor that may affect the WTP for health risk reduction. However, the results of these studies are somewhat contradictory (Hammitt and Haninger 2010). Balmford et al (2019) have introduced a new method in order to estimate the VSL, which accounts for its potential variation across age groups. According to the suggested so-called Chaining Method, the VSL is estimated separately for children and adults. Their results confirmed that VSL for children is significantly larger than its counterpart for adults.

In addition, according to theory it is expected that people in good health should have a higher WTP for reducing fatal risk. However, the effect of health status on the VSL is arguable, and empirical evidence seems to support that the VSL does not vary with health status (Alberini et al., 2004, 2006; Andersson and Treich, 2011). Mortality risk perception, along with risk characteristics have been found to be important determinants of the VSL. Notably, studies in developing countries tend to produce smaller estimates of the VSL than those in developed countries[86].

A great number of studies have addressed the validity and reliability issues of CVM surveys, and have provided several recommendations in order to produce more credible economic estimates of the value of environmental resources. Existing empirical CVM studies of mortality risks suffer from a number of shortcomings, the most serious of these is that respondents in general have difficulty in distinguishing

[86] For example, Gunatilake et al (2014) have compared the VSL estimates both in the US and in some developing economies. They found that the VSL in the US is in the range of $5 million to $12 million. However, the VSL in India is estimated as nearly Rs.15 million ($340,000), based on a sample of 1000 workers from Chennai and Mumbai.

between the different risk magnitudes, with the reason being that risk changes are usually expressed in units unfamiliar to them, for example, a 5 in 1000 reduction in the risk of dying from $PM_{2.5}$ air pollution (Bolt et al., 2005). Furthermore, applying CVM surveys either for valuing environmental quality or for estimating health risks in low and lower middle-income countries is confronted by many challenges, such as low literacy rates, and unfamiliarity with survey methodology. Bennett and Birol (2010), Christie et al (2012), and Rakotonarivo et al (2016) have indicated that the relatively low exposure of the respondents to surveys is the most serious problem. In addition, the low levels of environmental awareness within these countries represent another challenge to estimating the economic value of health, as people are often unaware of the environmental risk factors associated with a particular diseases or cause of death.

In conclusion, recent years have witnessed a growing interest in the valuation of environmental quality and health risks associated with pollution as a tool for informing environmental policies. However, studies conducted in developed countries still significantly outnumber those conducted in developing countries, with most of the later being concentrated in India and China. Only a few studies have been undertaken about estimating the WTP for improving air quality in Middle Eastern countries. Also, CV studies on valuing the health risks attributable to air pollution in developing countries are particularly limited.

Appendix (4A): Concepts of Ecosystem Value

The value of ecosystems

The value of ecosystems has been at the core of recent discussions on the role of valuation in environmental policy decision making. The debate about the value of ecosystems stems from two philosophical perspectives. The first supports the theory of *Non-Anthropocentric* value, which grants a moral standing to ecosystems and the services they provide, and emphasizes that ecosystems have value in themselves. On the other hand, *Anthropocentric* views, which include the economic approach to valuation, assume that only human beings have moral value, and therefore the value of ecosystems depends only on their contributions to human wellbeing. Accordingly, a wide array of possible values has been attributed to ecosystems in environmental literature. These values include the *Instrumental* value of an ecosystem's services, which is derived from the usefulness of an ecosystem's services in achieving human goals. On the other side, the *Intrinsic* value of an ecosystem reflects the recognition that nonhumans have worth or value that is independent of any contribution to human wellbeing, and thus it is also often referred to as the *Non-Instrumental* value. The Intrinsic value is closely related to the *Existence* value, which reflects individuals' desire to conserve and ensure the existence of a specific environmental resource. The concept of *Utilitarian* values originates from the ability of ecosystems' services to provide human welfare, and to increase the overall wellbeing of individuals (as defined by human preferences). There is a distinction between *Use* and *Non-Use* values of natural resources within environmental literature, based on whether there is a human interaction with the resource. Use values refer to those values linked to the current or potential future use of an environmental resource by individuals, while non-use values are derived from the continuous existence of the resource and are unrelated to its use (National Research Council, 2005).

The concept of *Economic Value,* which is the main focus of this study, is based on both the anthropocentric and the utilitarian approaches, in addition to individuals' preferences. It considers all instrumental values in addition to the existence value of a natural resource. Also, it assumes substitutability between the various kinds of value which contribute to individuals' utility or human welfare. Therefore, the economic valuation framework provides a means of measuring the magnitude of individuals' welfare gains and losses resulting from changes in ecosystem services, where the monetary value assigned by an individual to a natural resource can reflect that individual's preferences or his/her marginal willingness to trade money for environmental quality in a way that leaves his/her overall utility unchanged. Theoretically, the benefits associated with a given policy intervention are measured by increases in human wellbeing or utility. Although economic valuation does not always capture all sources or types of values (e.g., intrinsic values), using this framework helps to provide reliable information about the benefits of improvements in ecosystem services, or the costs of ecosystem degradation. This information represents an important consideration which influences the choice of an appropriate policy, and improves environmental decision making and policy design.

For example, when valuing air quality, the economic value of polluted air consists of health costs, including both the direct costs of health care and the indirect costs of sick leaves in workplaces, along with the costs of deteriorating soil, buildings, monuments, and infrastructure. Among these, avoiding health problems is considered to be the most significant value of air quality, and to represent the major benefit of policy interventions, through reducing environmental risks which result in either premature mortality or ill-health. Measuring the welfare losses relating to health risks due to a polluted environment can be done by estimating loss in income due to illness or premature death. However, the cost of illness values represents only the monetary costs of a disease, and do not include other costs such as pain and suffering, and the incapability to have the benefit of leisure time and activities. Estimates of the WTP measure an individual's preferences and therefore they provide values which reflect all aspects of the disease, including all the sources which may contribute to his/her utility or disutility. Many factors can affect the reliability and credibility of the WTP estimates for health risk reduction. A great body of empirical literature on valuing environment related health risk reductions (either mortality or morbidity) show that risk characteristics can have a significant impact on the value which people place on reducing health risks. Lack of familiarity with the risk being valued, and/or lack of understanding it can also significantly influence both the reliability and magnitude of the value which people place on reducing these risks, and can result in less reliable WTP estimates. On the other hand, experience with the risk being valued results in more precise and more credible estimates.

Chapter 5

Air Pollution and Willingness to Pay for Health Risk Reductions in Egypt: A Contingent Valuation Survey of Greater Cairo and Alexandria Households

1. Introduction

The root of the current environmental problems in Egypt can be traced back to the rapid economic development during the 1970s and 1980s of the past century, which was achieved at the expense of over-exploitation of natural resources and environmental degradation, accompanied by a marked negligence of environmental issues in development plans. For example, during that period a number of heavy polluting industries have emerged, some of which were located on the banks of the river Nile, which caused serious harm to both air and water resources, as well as to food production through soil contamination, thus posing many threats to public health. Efforts to improve the environment only began in 1994, when Egypt worked on improving the legal framework for environmental protection by drafting Law No. 4/1994 and its executive regulations. However, the formulation and implementation of environmental strategies still faced a number of constraints[87], such as the lack of an integrated approach in dealing with environmental issues within development strategies, the poor level of environmental awareness among stakeholders, and the lack of information about the economic value of environmental quality, where the latter is considered a significant barrier for the implementation of effective environmental strategies and pollution control plans.

Air pollution is a serious and a pressing environmental issue in Egypt and is considered to be among the major challenges facing the contemporary Egyptian society. Air quality measurements in Egypt[88] have been recording dangerous levels of lead, carbon monoxide, nitrogen dioxide, sulphur dioxide, Ozone, and suspended PM concentrations[89]. Consequently, air pollution takes a heavy toll on human health in Egypt, where it stands out as the biggest cause of deaths and disabilities linked to cardiovascular and respiratory diseases, along with certain cancers, e.g. lung, bladder, liver, and kidney cancers. Egypt is indeed one of

[87] These include financial obstacles and lack of resources for funding environmental projects, as most of the environmental projects in Egypt are funded by grants or easy loans offered by international organizations or foreign governments, e.g. the European Union and the Japanese government. Also, the public in Egypt are barely involved in the decision-making process, and there is a marked absence or ineffectiveness of environmental activist groups, who play a key role in many other countries in tackling environmental issues. These factors altogether create an atmosphere where there is a lack of proper enforcement of environmental legislations, and no incentive for the government to change their behaviour or strategy of ignoring environmental issues in favor of accelerating economic growth.

[88] EEAA, National Network for Monitoring Ambient Air Pollutants, 2015.

[89] Either PM_{10} or $PM_{2.5}$, with the latter being associated with the most serious health risks.

the top countries with respect to the burden of diseases due to air pollution and ranks first worldwide in terms of the number of deaths attributable to $PM_{2.5}$ air pollution (IHME, 2019).

As mentioned earlier, the lack of information about the value of air quality and the value of health consequences attributable to air pollution is one of the crucial barriers to developing effective policies for controlling air pollution in Egypt, where an effective policy intervention requires a better understanding of individuals' perceptions of air quality. The CVM can collect reliable information on such perceptions through stating individuals' preferences for select air quality improvement options, along with their ability and their WTP for such improvements. In Egypt, where there is a trade-off between economic growth and environmental quality, the decision makers and social planners can utilize such information in identifying some suitable set of air pollution control options, and in deducing and justifying the appropriate regulatory efforts (e.g. pricing policy for public utility services, scope for future tariff increases or subsidy reduction plans). This information also helps in setting out pollution control strategies in a way that ensures cost recovery for air pollution control projects, and hence the sustainability of pollution control plans, while maintaining a proper level of human welfare and environmental justice.

Although there is a large volume of literature on measuring the economic value of air quality using CVM, only a few studies have been undertaken about estimating the WTP for improving air quality in Middle Eastern countries. Also, CV studies on valuing health risks attributable to air pollution in developing countries are particularly limited[90] (Mahmud et al., 2019), where most of these studies have used the *Benefit Transfer* methodology for valuing air quality improvements, and health risks associated with poor air quality. For example, Abou-Ali and Belhaj (2005) have tested the validity of transferring benefits using the mean WTP for a 50 percent reduction in air pollution caused by road traffic between Rabat-Salé (Morocco) and Cairo (Egypt). A study by the World Bank has used the benefit transfer methodology for valuing the mortality from environmental health risks in Egypt, drawing on the empirical literature of VSL in the OECD countries (World Bank, 2019). To the best of our knowledge, the economic value of air quality resulting from industrial activities, and the value of a reduction in mortality risk attributed to air pollution has never been evaluated in Egypt using CVM before.

[90] Except for China and India.

1.1. Egypt Background

Egypt's population reached 100.4 million in 2019. The main metropolitan areas in Egypt are Greater Cairo and Alexandria. Cairo is considered to be one of the most overcrowded cities in the world (United Nations, 2018). In 2019, these two metropolitan areas have had an estimated combined population of more than 25 million, which is nearly 25% of the total population of Egypt, and had an average population density of 15.000 persons per Km^2. However, the population density is estimated to exceed 100,000 persons per Km^2 in some areas of Greater Cairo and Alexandria (WHO, 2010a). Air quality is deteriorating in Egypt in general, and in Greater Cairo and Alexandria in particular, where more than 80 per cent of the country's industrial activities take place. Due to the high population density, the number of people exposed to high levels of air pollution in both Greater Cairo and Alexandria is large.

As mentioned earlier, air quality measurements in Egypt have been recording high concentration levels of toxic gases such as lead[91] (7.2 $\mu g/m^3$ annual average), carbon monoxide (30 $\mu g/m^3$ hour average), nitrogen dioxide (58 $\mu g/m^3$ annual average), sulphur dioxide (49 $\mu g/m^3$ annual average), Ozone (180 $\mu g/m^3$ 8-hour average), and suspended PM concentrations, either PM_{10} (136 $\mu g/m^3$ annual average), or $PM_{2.5}$ (87 $\mu g/m^3$ annual average), all of which cause severe deterioration of air quality. This deterioration of air quality resulted from decades of unregulated transportation emissions, industrial activities in urban areas, and open-air burning of agricultural and municipal solid waste, in addition to natural factors such as the dusty environment and the scarce rainfall (Bassi and Nada, 2011; World Bank, 2017). The situation in Greater Cairo is the worst compared with the rest of the country, since Cairo has a poor dispersion factor because of its layout of tall buildings and narrow streets, which create a bowl effect. Furthermore, Cairo has many unregistered lead and copper smelters which heavily pollute the city, and also it is surrounded by agricultural areas which made it highly exposed to the practice of open air burning of agricultural waste, especially rice straw. The combination of these factors has resulted in the regular formation of haze over the city, dubbed by the locals as *"The Black Cloud"*, a condition that is especially pronounced during the fall.

Environmental Burden of Diseases in Egypt

Air pollution represents a persistent risk to human health in Egypt, where it is considered to be the main cause of deaths and disabilities attributable to cardiovascular and respiratory diseases, along with certain

[91] Safar and Labib (2010), indicated that lead concentration in some places such as Shubra El-Kheima, where most of lead smelters are located, may reach 23 $\mu g/m^3$.

cancers, such as lung, bladder, liver, and kidney cancers. As mentioned earlier, Egypt is one of the top countries with respect to the burden of diseases due to air pollution, and ranks first worldwide in terms of the number of deaths attributable to $PM_{2.5}$ air pollution (IHME, 2019). The annual premature deaths from ambient $PM_{2.5}$ exposure in Greater Cairo alone are estimated at about 12,100 to 13,000 in 2017[92]. About 59% of these deaths attributable to ambient $PM_{2.5}$ are due to ischemic heart disease (IHD), 14% are due to acute lower respiratory infections (ALRI), 13% are due to stroke, and 14% are due to Chronic obstructive pulmonary disease (COPD), lung cancer, and Type II diabetes (World Bank, 2019). In addition to mortality, ambient $PM_{2.5}$ in Greater Cairo is estimated to cause about 59,800– 61,800 YLD. This translates into 250 million days lived with disease in 2017.

The burden of diseases statistics in Egypt is shown in Table (5.1). The WHO data reveals that in 2019, Egypt ranked first worldwide in terms of bladder cancer, where a number of studies have emphasized the link between air pollution and the risk of bladder cancer (Castano-Vinyals et al., 2008; Loomis et al., 2014; Pedersena et al., 2018). Also, the country ranks fourth worldwide in terms of liver cancer, which has been found to be associated with air pollution as well (Deng et al., 2007; Pedersena et al., 2017). In Egypt, lung cancer is one of the common cancers, where it represents between 5%-7% of all cancers, with 47.2% of the patients being workers in construction and in cement production (El-Moselhy and Elrifai, 2018). Egypt ranks sixth worldwide with respect to inflammatory heart diseases, and ranks as one of the top ten countries in terms of deaths caused by coronary heart diseases. In 2019, Egypt ranked first worldwide with respect to liver diseases, and also as one of the top countries with a high prevalence rate of kidney diseases. According to recent estimations by the World Bank, 19,200 people have prematurely died and over 3 billion days were lived with illness in 2017 as a result of ambient $PM_{2.5}$ air pollution in Egypt (World Bank, 2019).

The estimated annual cost of the health effects associated with ambient $PM_{2.5}$ air pollution in Greater Cairo alone was equivalent to 1.35% of Egypt's GDP in 2017 (about 47 billion Egyptian pounds) (World Bank, 2019). Although air quality, in terms of $PM_{2.5}$ concentration, has improved in Greater Cairo over the period from 1999 to 2016 as a result of the EEAA efforts, these improvements were outpaced by population growth, which resulted in a net increase in annual deaths due to ambient $PM_{2.5}$ pollution.

[92] These estimates are based on annual ambient $PM_{2.5}$ exposure in the range of 66–86 μg/m3 with a central estimate of 76 μg/m3

Table (5.1): Burden of Diseases Statistics in Egypt

Disease	Deaths per 100,000 individuals
Bladder Cancer	7.98
Liver Cancer	27.42
Inflammatory Heart Diseases	23.63
Coronary Heart Diseases	2016.82
Liver Diseases	84.71
Kidney Diseases	32.88

Source: (World Bank, 2019).

The economic costs of dealing with pollution are increasing in Egypt, where the government is now witnessing a significant increase in the costs of medical care for treating cancer patients and individuals with respiratory diseases, where over 2.5 billion Egyptian pounds are spent annually in order to provide healthcare for Egypt's cancer sufferers of all ages especially children, which represents an increase of almost 40 percent since 1990 (World Bank, 2019).

1.2. Overview of study aims and methods

This work aims at estimating the WTP per household for improved air quality (or the implicit shadow price of air quality) in Egypt using CVM. As far as we are aware, the economic value of air pollution resulting from industrial activities, and the value of the reduction in mortality risk attributed to air pollution has never been evaluated for Egypt using CVM before. This work presents an attempt to fill this gap, given the seriousness of industrial air pollution in Egypt, especially in its two biggest metropolitan areas, Greater Cairo and Alexandria, where more than 80% of the country's industrial activities tack place. Therefore, we have conducted an internet-based survey in both locations in order to estimate the economic value of improved air quality and the value of saving one statistical life through improving air quality. In this work, we separate individuals' valuation of cleaner environment (or the WTP for improved air quality) from the WTP to avoid diseases (or reducing health risks associated with poor air quality). This was done by introducing two hypothetical scenarios, where the respondents were asked whether they wished to support some air pollution control project. The first scenario suggested the outcome of the project to be a reduction of $PM_{2.5}$ air pollution that is caused by industrial activities by 50%, in places where individuals live and work. The second scenario suggested the outcome of the project to be a reduction in the annual baseline mortality risk due to $PM_{2.5}$ air pollution related diseases (either by 10 in 10000, or by 5 in 10000). The main reason for this separation of individuals' valuations is to explore the impact of information on the willingness to support pollution control projects, in light of the low level of environmental awareness and lack of knowledge about the negative health consequences of air pollution among Egyptian households.

Accordingly, in this work we seek to answer a number of questions, mainly: What is the economic value of air quality in Egypt? And how do people perceive air pollution? Or equivalently, how much are Egyptian households willing to pay for an improvement in air quality? And how much are they willing to pay in return for some reduction in their risk of dying from adverse health conditions possibly caused by air pollution? Also, if people in Egypt are totally aware of the consequences of air pollution on their health, then would that affect their decision to support pollution control projects, or their stated WTP? Are factors like income and educational level, gender, age, level of exposure to air pollution, and suffering from a pollution related illness, play a role in having a positive WTP? Also, would these factors affect the amount the people are willing to pay?

In this work, we use the random utility maximization approach (RUM) in order to model households' preferences for air quality. This consumer preference model represents the theoretical framework through which CVM responses are to be interpreted. The statistical analysis of these responses provides the framework for measuring the WTP, which largely depends on the elicitation format or survey questions, and here we have elected to use the *double-bounded* dichotomous choice approach. For empirical analysis, we use alternative Parametric and non-Parametric methods, such as the Interval-Data model, Bivariate Probit model, and Turnbull estimator, in order to estimate households' WTP for improving air quality, and for reducing the health risks associated with air pollution, both in Greater Cairo and in Alexandria. Also, in order to assess the relationship between households' WTP on one hand, and various factors such as environmental awareness, income, age, gender, education, and health status (illnesses suffered due to air pollution) on the other hand. The VSL is calculated based on both the WTP to avoid illness and the percentage of risk reduction.

The rest of this chapter is organized as follows: Section (2) introduces a consumer preference model for an improvement in air quality. Section (3) describes the design of the survey that was conducted in order to measure the economic value of improving air quality and reducing mortality risks associated with air pollution in Egypt. Section (4) introduces the empirical analysis and the main findings. Section (5) discusses the empirical findings and study limitations. Finally, Section (6) concludes and introduces some thoughts and implications relevant to the policy making process.

2. Modelling individuals' preferences for air quality improvements

Based upon a consumer choice model, we employ CVM in order to measure the monetary value which individuals place on a specific improvement in air quality, q. We assume that the utility function of an individual can be expressed as: $u(x, q)$[93], where x denotes the vector of various market goods included in his/her bundle. The indirect utility function corresponding to this direct utility function can be written as: $v(p, q, y)$[94], where p refers to the vector of prices of market goods, and y denotes the personal income. In order to measure the economic value of an improvement in air quality, we assume that the government plans to implement some new environmental policy, which will change the status of air quality from q^0 *to* q^1. Therefore, the utility function for an individual changes from $u^0 \equiv v(p,q^0,y)$ to $u^1 \equiv v(p,q^1,y)$, where $u^1 > u^0$. We also assume that individuals need to carry some part of the cost of implementing such policy, c, thus a rational individual will accept the policy only if: $v\,(p, q^1, y - c) \geq v\,(p, q^0, y)$.

The value of this air quality improvement in monetary terms can be expressed by the two Hicksian measures, the compensating variation, C, and the equivalent variation, E, which satisfy the condition: $v(p,q^1,y\text{-}C) = v(p,q^0,y)$ and $v(p,q^1,y) = v(p,q^0,y+E)$, where $C > 0$, and $E > 0$. Here, C measures the individual's WTP for such improvement, and E measures the WTA to forgo it. Given that measuring the WTP is the main scope of this work, we will focus on the compensating variation, which can be expressed as: $C = (q^0, q^1, p, y)$. This function implies that the compensating variation depends on the starting and the anticipated values of q, along with the values of both p and y at which the improvement of q occurs. Correspondingly, the WTP function can be written as: $WTP = (q^0, q^1, p, y) = [C = (q^0, q^1, p, y)]$, where $C \geq 0$. Assuming that the individual's expenditure function takes the following form: $y = m(p, q, u)$[95], where $m(p ,q, u) > 0$, the compensating variation can be defined in terms of this expenditure function as: $C = m\,(p, q^0, u^0) - m\,(p, q^1, u^0)$, which means that $C = y - m\,(p, q^1, u^0)$. This implies that the compensating variation or the WTP for an improvement in air quality is bounded by y *(or* $C < y$*)*.

The consumer preference model defined above represents the theoretical framework through which the CVM responses can be interpreted. The statistical analysis of these responses provides the framework for measuring the WTP, which largely depends on the elicitation format or survey questions. The indirect utility function has often been used within the CVM literature in analyzing survey responses (Carson and Hanemann, 2005), particularly in a RUM modelling framework. Although individuals are assumed to perceive their preferences with certainty, these preferences may contain some characteristics, related to either the individual or to the item being valued, which are unobservable, and can signal the variation in preferences among the respondents, in addition to indicating the existence of measurement errors or

[93] This function is assumed to be increasing and quasi-concave in x, and increasing in q.

[94] This function is assumed to be homogeneous of degree zero in both p and y, increasing in y, non-increasing and quasi-convex in p, and increasing in q.

[95] This function is assumed to be increasing in u, concave and homogeneous of first degree in p, and decreasing in q.

missing data (Manski, 1977). Therefore, the survey responses should be treated as a random variable, and a stochastic term should be introduced into the utility model (McFadden, 1974).

The linear form of this model as proposed by McFadden and Leonard (1993) takes the following form:

$$v_q = \alpha_q + \beta_q y + \varepsilon_q \quad q = 0,1, \qquad (2.1a)$$[96]

where y is the respondent's income, $\alpha \equiv \alpha_1 - \alpha_0$, and $\beta_1 = \beta_0 \equiv \beta > 0$, and where both ε_0 and ε_1 are random variables with zero means.

In this case, the corresponding formula for the compensating variation takes the following form:

$$C = \frac{\alpha + \eta}{\beta} \qquad (2.1b)$$

where $\eta \equiv \varepsilon_1 - \varepsilon_0$. It follows that C has the same distribution as ε.

Given the assumption of a utility maximizing response to the survey question, the WTP cumulative distribution function (CDF) for an individual specifies the probability that the individual's WTP for an improvement in air quality is less than a certain amount, A. The CDF can be expressed as: $G_C(A) \equiv Pr(C \leq A)$, where the corresponding density function is $g_C(A)$.

As mentioned earlier, the statistical analysis of survey responses varies with the form of survey question. Our selected elicitation format is the *double-bounded* dichotomous choice, where the respondents are asked two closed-ended questions with the bid amount in the second question being conditional on the response to the first question, e.g. would you vote to support the change from q^0 to q^1 if it would cost you $\$A$? If the respondent answered "yes" to the first valuation question, the question is then to be repeated with a higher value for $\$A$, equal to $\$A^u$, if the respondent answered "no", the question is then to be repeated with a lower value for $\$A$, equal to $\$A^d$.

In this case, where each respondent (*i)* is being asked two questions, there are four possible outcomes: the answer for both questions is "yes", the answer for both questions is "no", the answer for the first question is "yes" followed by a "no" for the second question, and the answer for the first question is "no" followed by a "yes" for the second question. Following Alberini (1995b), the general formulae for the probabilities for these responses are:

[96] See Carson and Hanemann (2005) for the full derivation of this equation.

$$
\left.
\begin{aligned}
&Pr(\text{Response is yes/yes}) = Pr(C \geq A^u) \equiv 1 - G_C(A^u),\\
&Pr(\text{Response is no/no}) = Pr(A^d \geq C) \equiv G_C(A^d),\\
&Pr(\text{Response is yes/no}) = Pr(A^u \geq C \geq A) \equiv G_C(A^u) - G_C(A),\\
&Pr(\text{Response is no/yes}) = Pr(A \geq C \geq A^d) \equiv G_C(A) - G_C(A^d).
\end{aligned}
\right\} \quad (2.2)
$$

The binary-valued indicator variables for these expected responses can be denoted as:

$$
\left.
\begin{aligned}
&I^{yy} = 1(i\text{th respondent response is “yes-yes”})\\
&I^{nn} = 1(i\text{th respondent response is “no-no”})\\
&I^{yn} = 1(i\text{th respondent response is “yes-no”})\\
&I^{ny} = 1(i\text{th respondent response is “no-yes”})
\end{aligned}
\right\} \quad (2.3)
$$

where I(•) is an indicator function, whose value is one if the argument is true, and zero otherwise. Here, the CDF can be expressed as: $G_C(\bullet, \theta)$, where θ is the vector of parameters. Given a sample of N respondents, where A_i,A_i^u, and A_i^d are the bids used for the i^{th} respondent, the log-likelihood function takes the form:

$$
\begin{aligned}
\ln L = \sum_{i=1}^{N} \; &\{I_i^{yy} \ln[1 - G_c(A_i^u, \theta)]\\
&+ I_i^{nn} \ln[G_c\left(A_i^d, \theta\right)]\\
&+ I_i^{yn} \ln[G_c(A_i^u, \theta) - G_c(A_i, \theta)]\\
&+ I_i^{ny} \ln\left[G_c(A_i, \theta) - G_c\left(A_i^d, \theta\right)\right]
\end{aligned} \quad (2.4)
$$

The main advantage of the double-bounded approach is to increase the statistical information around the WTP measure introducing lower and upper bounds (Carson and Steinberg, 1990; Hanemann et al., 1991). However, McLeod and Bergland (1999) and Von Stackelberg and Hammitt (2009), noticed that in some cases the responses to the follow-up bids are inconsistent with the responses to the initial bid, and that in some other cases the responses to the second bid have been influenced by the first bid proposed.

3. Study Design, Questionnaire and Sampling

The study employs an Internet-Based Survey, mainly targeting households in the Greater Cairo and Alexandria districts, where it elicits household's preferences for improved air quality, and for health risk reduction, as a result of implementing selected environmental policy options. Respondents had access to the electronic questionnaire by means of an internet browser application provided by Qualtrics software. This questionnaire is self-administered by the respondents who read the questions on the computer screen and entered their responses without the involvement of an interviewer. The questionnaire has been translated into Arabic such as to ensure the full understanding of the questions by the participants. Each questionnaire calls for one respondent only, acting as the sole representative of a single household.

The collection of data has been done by Marketeers, an Egyptian market research company[97], which was hired for that purpose. Sampling has been done using the Quota Sampling method, where the sample population (1051 households)[98] has been divided into subgroups proportional[99] to gender[100] (65% of the respondents are males and 35% are females), age (47% of the respondents are in the age group between 24 to 39 years, 47% of the respondents are in the age group 40-59 years, and 6% of the respondents are above 60 years old), and location (65% of respondents are from Greater Cairo and 35% are from Alexandria).

The fieldwork of this survey has taken approximately three months (from the 25th of November 2020 to the 15th of February 2021). The Arabic language version of the survey questions has been tested first on a select focus group in order to see how much these potential respondents would understand the questions. In addition, during the pre-testing phase, we have conducted another pilot study where 25 participants have been invited to a telephone interview by the agency in order to give their evaluation and comments on the survey questions. The final version of the questionnaire reflects inputs from both of these two focus groups.

3.1 Survey Design

While the specifics of survey design may vary according to the nature of study at hand, the survey instruments must typically contain some basic elements. Following the standard approach in the literature and the methodology suggested by Carson and Hanemann (2005), our questionnaire consists of seven elements: (1) an introductory section identifying the general topic of the study, (2) a section containing some demographic questions that reflect the respondents' age, gender, and residency, where these three criteria are used as screening questions for the sample. In Section (3) of the survey, the respondents have been quizzed for their knowledge about environmental issues in general, and about environmental problems in Egypt in particular, along with the relationship between these and potential health problems. Also, the respondents have been asked to rank four sources of health risks, food contamination, air pollution, water pollution, and traffic accidents in terms of their perceived severity. This question was

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[97] The company has been working in Egypt for more than 26 years. It is a member of the European Society for Opinion and Marketing Research (ESOMAR) and works under both the EU General Data Protection Regulation (GDPR) and the Egyptian personal data protection law No. 151 of 2020.kirs

[98] The total number of responses received was 1060, out of which 1051 responses were deemed valid.

[99] According to the last Egyptian census.

[100] Although the percentages of males and females in Egypt are nearly equal (49% and 51%, respectively), decision-making within Egyptian households is mostly dominated by males, even when a woman is the head of the household, and this is particularly true within the lower-middle and low-socioeconomic classes. So, it was hard to find a head of a household who is both a female and who also has the liberty to make financial decisions.

designed in order to evaluate the respondents’ attitudes towards air pollution compared to other sources of risk. The main purpose of the questions in this section was to get some knowledge about households' realizations of the current environmental problems and their potential impact on their health conditions. The responses to these questions were used as an indicator of environmental awareness, and in investigating the respondents' risk perception for air pollution.

Section (4) of the survey presented the CVM scenarios, which included a full description of what the project aims to accomplish, how it would be implemented and paid for, followed by the questions about the respondent's preferences for pollution control options. The participants were asked whether they wish to support some air pollution control project, through either one of two hypothetical scenarios which were randomly presented to them. The first scenario suggests the outcome of the project to be a reduction by 50% of air pollution (specifically $PM_{2.5}$ air pollution) resulting from industrial activities in places where individuals live and work. The second scenario suggests the outcome of the project to be a reduction in the annual baseline mortality risk, either by 10 in 10000 or by 5 in 10000, resulting from $PM_{2.5}$ air pollution related diseases.

The first scenario outlines the significance of industrial pollution as one of the most important contemporary environmental issues in Egypt. We have chosen suspended PM smaller than 2.5 microns in diameter or $PM_{2.5}$ as the targeted pollutant, because it is the most concerning air pollutant in Egypt. Under this hypothetical scenario, polluting industries are to be relocated to remote areas, far from population centres. That project is to be funded using governmental revenues collected through raising general sales tax rates on marketed goods, which would consequently increase their prices. These higher prices for marketed goods due to an increase in the general sales tax, paid by the respondents over a ten-year period, represents the payment vehicle through which individuals would express their WTP for improved air quality. For a detailed discussion of our reasons for selecting an increase in the general sales tax as a payment vehicle, see Appendix (5B).

This sub-sample, which represents the first scenario where the respondents were asked about their WTP for a 50% reduction in the ambient $PM_{2.5}$ air pollution that is caused by industrial activities, is divided into two approximately equal sub-groups. For the first sub-group, designated as group (1), no information was given to the respondents about the impacts of air pollution on their health. This means that the respondents in this sub-group have expressed their preferences for cleaner air based on their own perceptions of the harm of pollution, which depends on their own knowledge, experience, and whether they think about the impact of their decisions on future generations and on other countries. In other words, the respondents within this sub-group have their own subjective views about the detrimental impact of air pollution, and the importance of pollution control plans, and these views are expected to reflect individuals' perceptions of air pollution, along with their level of environmental knowledge.

On the other hand, in the second sub-group of this scenario, designated as group (2), the respondents were provided with some information about the consequences of air pollution on their health, and the current burden of disease attributable to air pollution in Egypt, such as to examine whether providing them with this information[101] will affect their decision to support pollution control projects. This means that the respondents in this sub-group were well informed about the adverse health impacts of air pollution. In this case, assuming the respondents fully believed the information provided, their decision to support the pollution control project would have actually been a decision for reducing their health risks associated with air pollution.

The second scenario describes the health risks from exposure to $PM_{2.5}$. The baseline pollution risk is the annual deaths of 1192 for each 100,000 persons, where this figure is obtained from the CAPMAS for the year 2017. Similar to the first scenario, an increase in the prices of purchased goods, and hence the monthly costs of living, due to regulating industrial air pollution is chosen as the payment vehicle[102] by which individuals would express their WTP for reducing the risk of premature mortality attributed to air pollution. In order to account for the scope effect in the WTP responses, we use a split-sample CVM design. We test the sensitivity of the WTP responses to the probability of risk or scope changes by asking the respondents about their WTP for two different levels of risk reductions. Thus, this sub-sample, which represents the second scenario, is divided into two approximately equal sub-groups as well.

In both sub-groups, the respondents were provided with information about the adverse impacts of air pollution on their health. Those in the first sub-group, designated as group (3), were given a reduction of 10 in 10000 in the annual baseline risk for mortality from diseases related to air pollution. Meanwhile, for the second sub-group, designated as group (4), the risk is reduced to 5 in 10000 in the annual baseline risk. In other words, for this sub-sample we aimed at measuring how much households in both Greater Cairo and Alexandria value lowering the health risks associated with air pollution, through estimating the marginal rate of substitution between income and the mortality risk associated with air pollution-induced diseases, or the VSL.

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[101] The importance of well-informed respondents has been frequently emphasized in CVM literature.

[102] Some studies suggested using the price of a private good as a payment mechanism through which the respondents can reduce their own risk of dying. They argued that using private goods avoids the strategic bias associated with using public goods or programs, such as free riding behaviour, and bias resulting from the high number of protest responses due to doubts about the effectiveness of the program.

Respondents have been asked (in all four groups) an initial dichotomous choice question about their willingness to support some pollution control projects, where they have been asked whether they accept an increase in their monthly cost of living as a result of implementing some pollution control procedures. For those who expressed their unwillingness to support the project (who answered "no"), they were asked one further follow-up question about their reason of refusal, where they would select one out of five suggested motives. Those respondents who answer "yes" are to be asked whether they accept an increase in their cost of living by a certain amount of money.

The positive WTP was elicited using a double-bounded dichotomous choice question format (Hanemann et al., 1991). As explained earlier at the end of Section (2), the respondents were randomly assigned a first bid amount, with predetermined lower or higher follow-up bids being offered depending on their answer to the initial bid. For respondents whose answer was "no" for both the initial and second bids, they have been asked to express the maximum increase in monthly cost of living that they would accept in order to support the project using an open-ended question format. The assigned bid vectors were: (LE 100, LE 50, LE 200), (LE 200, LE 100, LE 300), (LE 300, LE 200, LE 400). These are equivalent to an increase in the annual costs of living by 600, 1200, 2400, 3600, and 4800 LE (about 37, 74.5, 149, 224, and 298.5 US$ respectively)[103]. Respondents have been informed to carefully consider their answers and their budget constraints.

Figure (5.1) illustrates the flow of the CV questions used in order to establish households' WTP. As mentioned earlier, based on the amount of information embedded in each scenario about the negative impact of air pollution on health, the sample has been divided into two sub-samples (four sub-groups), The respondents in all the four sub-groups have been asked an initial question about their willingness to support air pollution control projects before directly asking them to value either the improved air quality or mortality risk reduction.

[103] These bid amounts have been revised according to feedback from the focus group and the pilot survey.

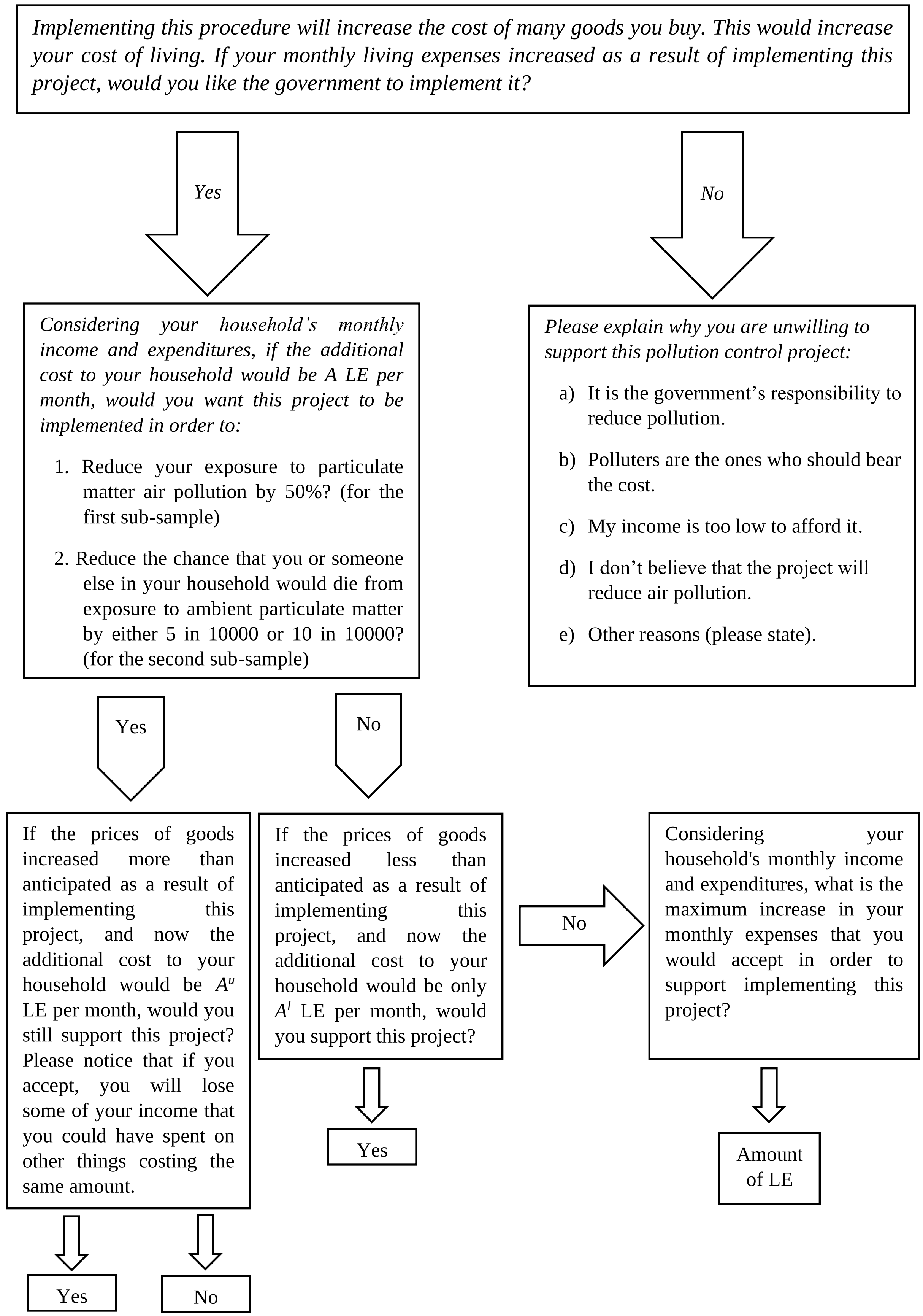

Figure (5.1): The general form of the CV questions used in the survey.

Section (5) of the survey contained demographic questions that reflect the respondents' characteristics which may affect their risk management attitudes such as their income, educational level, marital status, having children, household size, and health status. Section (6) of the survey has the main purpose of obtaining some indicators regarding the economic and health burden of air pollution. This section includes questions regarding whether each respondent suffers from any air pollution-related problems or not, their perceived exposure to air pollution (measured in hours), their workplace (indoors or outdoors), their subjective view of the current air pollution situation, and any possible monetary expenses paid out of pocket for recovering from health problems linked to air pollution. The expenses here are considered to be costs induced by air pollution[104], which are classified into a monthly medical cost, and lost income due to absence days, in addition to information about any possible use of an air purifier and the cost associated with it, which can reflect the respondents' revealed preference for improved air quality, where all these costs are considered to be an indirect WTP for individuals (Courant and Porter, 1981; Calthrop and Maddison, 1996). Section (7) of the survey contains debriefing questions with the purpose of ascertaining how well the respondents understood the scenarios.

4. Empirical Findings

Our sample consists of 1051[105] Egyptian households from both Greater Cairo and Alexandria[106] divided into two approximately equal sub-samples. See Figure (5.2).

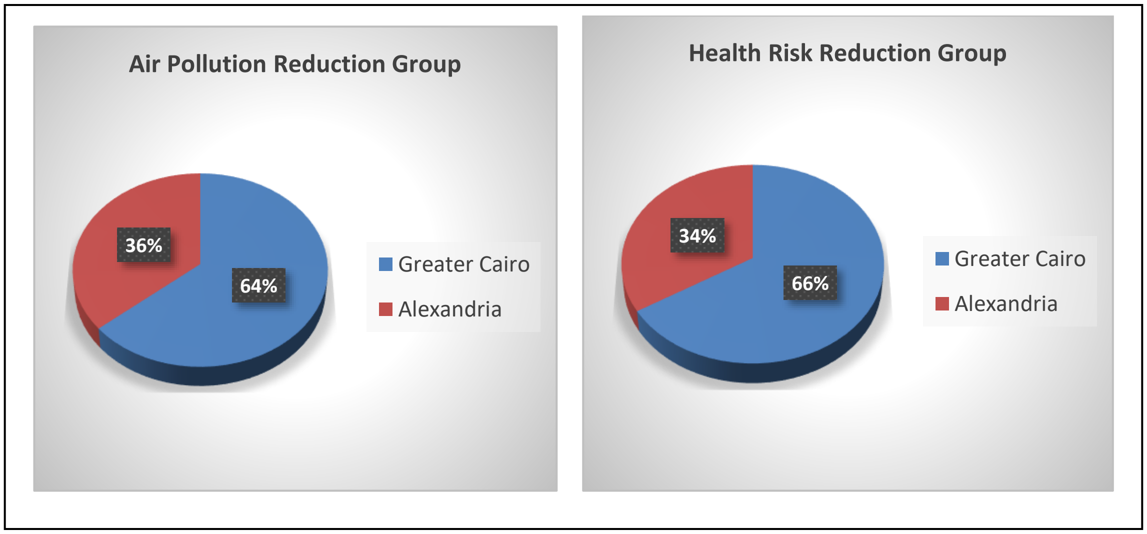

Figure (5.2): The Distribution of Responses by residency.

[104] This information gathered through the survey about the respondents' indirect WTP could be used for dose-response methods, however this is beyond the scope of the current study.
[105] The total number of responses is 525 for the air quality sub-sample and 526 for the health risk sub-sample.
[106] Data has been collected from 47 districts in Greater Cairo metropolitan area and 40 districts in Alexandria.

Figure (5.3) illustrates the distribution of survey responses by sub-samples and sub-groups. The analysis of the survey responses shows that about 67.5% of the households in the first sub-group, where no information has been given to the respondents about the adverse health effects of air pollution have expressed a positive willingness to support pollution control projects compared with nearly 75% of the households in the other three sub-groups, where the respondents are presumably well informed about the adverse health impacts of air pollution.

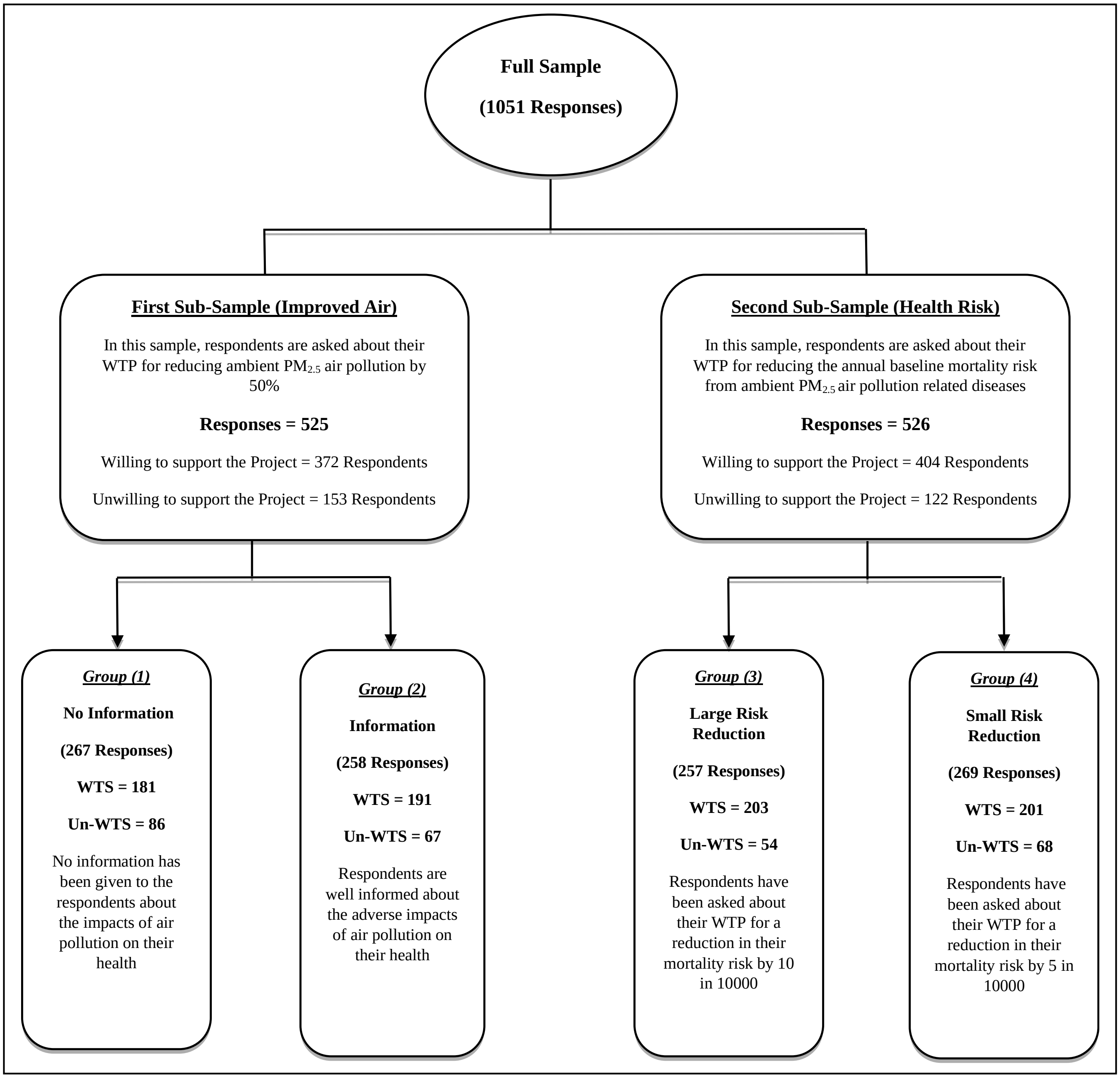

Figure (5.3): The Distribution of Survey responses by sub-samples and sub-groups.

A Kruksal-Wallis H test was conducted in order to determine whether the willingness to support the pollution control projects was different for the group that didn't receive information about the negative health consequences of air pollution. The test showed that there was a statistically significant difference in the WTS for pollution control projects between the sub-groups that received information and the one which didn't receive information, as $\chi^2(1) = 6.762$, and $p = 0.0093$. This significant difference in the percentages of households who are willing to support pollution control projects can be attributed to the impact of information. On the other hand, for those who were unwilling to support the projects, their main reason was their belief that the government, along with the polluters, are responsible for controlling pollution.

The percentage of females who have a positive WTP for improved air quality is higher than the percentage of males by about 2%, meanwhile both males and females have shown a similar positive WTP for health risk reduction. Low income is a significant reason for females not to support pollution control projects (for about 29% of them). Although exploring the impact of income inequality on the WTP is beyond the scope of this work, it is worth mentioning that comparing males and females' incomes within this sample shows some sizable gender pay gap in Egypt.

In Greater Cairo, the percentage of households who show a positive WTP for both improved air quality (77%), and health risk reduction (82%) is significantly higher than those in Alexandria (60% and 67%). This reflects the fact that people in Greater Cairo are more exposed to air pollution. Low income is the main reason for the respondents' unwillingness to support pollution control projects in Greater Cairo in both sub-samples, as 30% of the households have reported that as their reason for unwilling to pay for improved air quality, and 24% of the households have reported it as their reason for unwilling to pay for health risk reduction.

The percentage of households which show a positive WTP for improved air quality within the age group 24-39 years is higher than its counterparts in both the 40-59 years and the 60+ years age groups (80% compared with 68% and 23%). Low income represents a significant reason for not supporting pollution control projects within this age group, as 35% of the households have reported low income as their reason for their unwillingness to pay. Regarding the WTP for health risk reduction, 82% of the households within the age group 24-39 years have a positive WTP, compared with 77% within the age group 40-59 years, and 37% among the age group 60+ years.

The qualitative analysis of the answers to the questions testing environmental awareness shows that Egyptian households seem to have a low level of environmental knowledge, as the average percentage of correct answers for the questions testing such knowledge was only 27%. Apparently, their main sources of environmental information are public websites and social media, while only 18% of the households get their information about air pollution from official websites. From the point of view of Egyptian households, water pollution and traffic accidents are perceived to be more serious health risks than air pollution. Almost 34% of the households have rated air quality in their residential areas as poor and very poor, and about 44% have reported air pollution in their workplaces as poor and very poor. However, only 10% of the households have an air purifier installed at their homes.

Regarding the health burden of air pollution, 22% of the representatives of households have reported that either they or a member of their household have respiratory diseases, 19.8% have cardiovascular diseases, 9.5% have cerebrovascular diseases, 5.4% have lung cancer, 3.3% have bladder cancer, 10.3% have kidney diseases, and 14.4% have liver diseases. Also, about 28.5% of the respondents have reported the occurrence of multiple diseases within their households. Regarding the economic burden of air pollution, 59% of the households do not have health insurance, and pay for their medical expenses out of pocket. Also, 60% of the households have reported some days of absence from work because of their illness or the illness of their family members, ranging between 1 day and more than 5 days a month, and most of the respondents' working hours per week ranged between 40 and 52 hours.

4.1. Statistical Analysis

In our statistical analysis, alternative statistical models are suggested in order to examine the consistency of the responses with economic theory, and in order to estimate both the WTP for improved air quality and the VSL, in addition to investigating the relationship between the respondents' characteristics and the amount they are willing to pay, and also to explore the factors that affect Egyptian households' willingness to support pollution control projects (the probability of expressing a positive WTP), along with the role that information plays in this regard.

A detailed description of the variables characterizing the respondents is given in Table (5.2). These include demographic characteristics, socio-economic status, health status of household members, level of environmental knowledge, environmental risk perception, and the air pollution status in their residential and working areas from a subjective perspective.

Table (5.2): Descriptive statistics of the Survey Responses

Variable	Description	Obs	Mean	Std. Dev.	Min	Max
WTS	Willing to support = 1, Unwilling to support = 0	1,051	0.74	0.44	0	1
Bid1	100, 200, 300	776	200	81	100	300
Bid2	50, 100, 200, 300, 400	776	255	100	50	400
Answer1	Yes to first bid = 1, No to first bid= 0	776	0.765	0.42	0	1
Answer2	Yes to second bid = 1, No to second bid= 0	776	0.59	0.49	0	1
Residency	Greater Cairo = 1, Alexandria = 0	1,051	0.648	0.478	0	1
Gender	Male = 1, Female = 0	1,051	0.65	0.48	0	1
District-Type	Categorical variable: Residential = 1, Residential area with small industries = 2, Both residential and industrial = 3	1,051	1.8	0.81	1	3
Residential	Residential = 1, Else = 0	1,051	0.47	0.50	0	1
Residential-small-industries	Residential area with small industries = 1, Else = 0	1,051	0.29	0.46	0	1
Both-residential-industrial	Both residential and industrial = 1, Else = 0	1,051	0.24	0.43	0	1
Age	Categorical variable: 24-39 = 1, 40-59 = 2, 60+ = 3	1,051	1.6	0.61	1	3
Age Group (1)	24-39 = 1, Else = 0	1,051	0.47	0.50	0	1
Age Group (2)	40-59 = 1, Else = 0	1,051	0.46	0.50	0	1
Age Group (3)	60+ = 3, Else = 0	1,051	0.066	0.25	0	1
Years of Schooling	Number of years of schooling	1,051	15.8	1.2	6	17
Income level	Categorical variable: Low Income = 1, Middle Income = 2, High Income = 3	1,051	2.2	0.77	1	3
Low-Income	Low Income (less than 3200 LE) = 1, Else = 0	1,051	0.23	0.42	0	1
Middle-Income	Middle Income (from 3250 LE to 6000 LE) = 1, Else = 0	1,051	0.38	0.49	0	1
High-Income	High Income (More than 6000 LE) = 1, Else = 0	1,051	0.39	0.49	0	1
Marital Status	Categorical variable: Married = 1, Single = 2, Divorced = 3, Widowed = 4	1,051	1.45	0.76	1	4
Children	Have children = 1, Doesn't have children = 0	1,051	0.66	0.47	0	1
Number of children	Number of children	1,051	1.6	1.38	0	6
Household size	Number of persons living in the same house	1,051	4.0	1.4	1	7
Health status	Have environmental-related disease = 1, Doesn't have environmental-related diseases = 0	1,051	0.44	0.49	0	1
Number of Diseases	Number of diseases experienced within the household members	1,051	1.06	1.8	0	15
Air-quality-residency	Air is rated as good or v. good = 1, Else = 0	1,051	0.345	0.475	0	1
Air-quality-work	Air is rated as good or v. good = 1, Else = 0	1,051	0.43	0.50	0	1
Protective Behaviour	Have an air purifier = 1, Doesn't have air purifier = 0	1,051	0.10	0.30	0	1
Having Health Insurance	Categorical variable: Have full health insurance coverage = 1, Have partial health insurance coverage= 2, Doesn't have health insurance coverage = 3	1,051	2.4	1.80	1	3

Full Insurance	Have full health insurance coverage = 1, Else = 0	1,051	0.205	0.40	0	1
Partial Insurance	Have partial health insurance coverage = 1, Else = 0	1,051	0.20	0.40	0	1
No Insurance	Doesn't have health insurance coverage = 1, Else = 0	1,051	0.59	0.49	0	1
Job type	Outdoor job = 1, Indoor job = 0	1,051	0.855	0.35	0	1

4.1.1. Pooled Sample

In the analysis of the full sample, we first explored the consistency of the responses with economic theory, and then we explored the factors that affect households' decisions on supporting air pollution control projects, focusing on the role that information about health risks associated with air pollution plays in this regard.

The percentage of respondents who were willing to support pollution control projects within Egyptian households in general (in the full sample) equals about 73.8%[107] (776 households). Figure (4) shows that, as expected, the proportion of positive answers goes down as the bid amount goes up, where the percentages of "yes" responses equal nearly 90.6%, 72%, and 67.3% for the bid amounts of 100LE, 200LE, and 300LE, respectively.

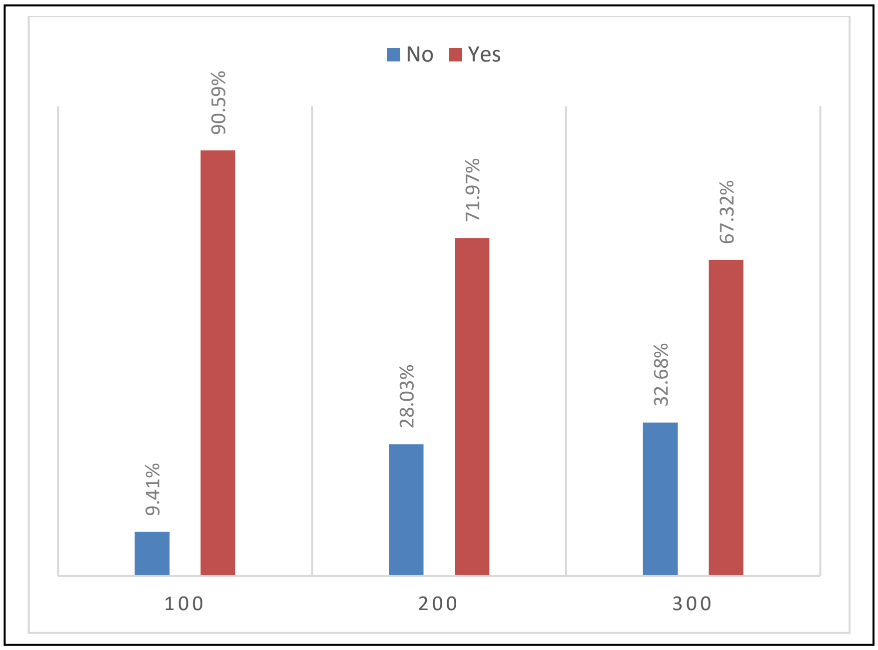

Figure (5.4): Responses to the first bid

[107] The number of households who expressed their unwillingness to support the project is 275 respondents (nearly 26%).

Results presented in Table (5A.1) in Appendix 5A are obtained from the estimation of a Bivariate Probit model for the pooled sample, with only bid prices as covariates. These results show that the bid variables are statistically significant with a negative sign, which refers to the probability of a positive answer going down as the bid goes up. The correlation between the error terms of the two questions is estimated by the correlation coefficient ρ. The value of ρ for this model is 0.37, which indicates a weak correlation between the response-generation functions. The role that the value of ρ can play in choosing the appropriate statistical model for analysing the data, will be discussed in more detail later in this chapter.

The Maximum Likelihood (ML) method was employed in order to estimate the parameters in a Probit regression model. As such, the model assesses the relationship between various factors and households' willingness to support pollution control projects. The dependent variable is designed as a dichotomous dummy because of assuming whether the respondent is willing to support the project or not. The model is represented by the following equation:

$$C_i = \beta_i X_i + e \qquad (4.1)$$

where C_i equals 1 if the respondent is willing to support the project and equals zero otherwise, X_i is the vector of independent variables (age, gender, income, educational level, exposure to air pollution, environmental awareness, and health status), β_i denotes the coefficients to be estimated, while e represents the disturbance error term, and $i = 1,2,3,... N$, where N is the number of respondents. The likelihood ratio index was measured as an indicator of the goodness of fit for this regression model.

Estimation results are shown in Table (5.3). In this model, a variety of factors have a significant positive influence on Egyptian households' decisions to support air pollution control, including having information about the negative health consequences of air pollution, having higher income, and working an outdoors job. Also, residents of Greater Cairo as well as people of younger age (less than 40 years old) are more likely to support pollution control projects compared to Alexandria's residents and to elderly people.

In addition, living in highly polluted areas has been found to positively correlate with the willingness to support pollution control efforts. We have classified the districts where the survey has been conducted into three categories, according to their level of exposure to possible sources of pollution, both in Greater Cairo and in Alexandria. The first category is residential areas which have moderate or low population densities and limited nearby sources of pollution, such as Al-Maadi in Greater Cairo and San Stephano in Alexandria. The second category is residential areas with small industries (such as lead smelters) which have high population densities, high traffic volume, and are downwind from industrial sources of pollution, such as Shobra El-Kheima in Greater Cairo and Camp Shizar in Alexandria. The third category is residential-industrial areas which have moderate population densities, and many nearby sources of pollution, especially cement, steel, or other heavy industries, such as Helwan in Greater Cairo and Al-Aamiryah in Alexandria.

On the other hand, the probability of expressing a positive WTP for controlling air pollution was found to decrease with age (more than 60 years old), having low income, being in a good health status (not suffering from air pollution-related diseases), having health insurance coverage, and whether the respondent doesn't consider air pollution to be a problem (has rated air pollution in his area of residence as good or very good), or is applying some protective measures (having an air purifier installed in his/her house). Although it was not found to be statistically significant, educational level still displays some positive relationship with the willingness to support pollution control projects.

Table (5.3): Factors affecting the WTS for pollution control projects in the pooled sample

WTS	Coef.	[95% Conf. Interval]		Marginal Effects
Information	0.35**	0.15	0.55	0.098***
	(0.10)			(0.029)
Residency	0.47***	0.29	0.66	0 .132***
	(0.095)			(0.025)
Gender	0.03	-0.19	0.25	0.008
	(0.11)			(0.030)
Residential	0.076	-0.13	0.29	0.021
	(0.11)			(0.029)
Both residential and industrial	0.27**	0.017	0.53	0.076**
	(0.13)			(0.036)
Age Group (1)	0.34**	0.14	0.54	0.095***
	(0.10)			(0.026)
Age Group (3)	-1.21***	-1.55	-0.86	-0.336***
	(0.175)			(0.048)
Years of Schooling	0.04	-0.039	0.12	0.011
	(0.04)			(0.011)
Low Income	-0.61**	-0.94	-0.28	-0.171***
	(0.17)			(0.046)
High Income	0.32**	0.10	0.54	0.089***
	(0.11)			(0.031)
Good Health	-0.17*	-0.37	0.024	-0.049*
	(0.10)			(0.028)
Poor Health	-0.15	-0.46	0.16	-0.042
	(0.16)			(0.047)
Air Quality (residency)	-0.31**	-0.52	-0.10	-0.086***
	(0.11)			(0.029)
Protective Behaviour	-0.30**	-0.60	-0.003	-0.084**
	(0.15)			(0.042)
Having Health Insurance	-0.26**	-0.48	-0.035	-0.072**
	(0.11)			(0.032)
Job type	0.43***	0.19	0.68	0.12***
	(0.12)			(0.034)
Constant	-0.82	-2.11	0.46	
	(0.65)			
Number of Obs. = 1,051				
Log likelihood = -520.8				
Pseudo R^2 = 0.14				
LR chi2 = 166.58 Prob > chi2 = 0.000				

Robust Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

In addition, we use both Probit and Logistic regressions in order to explore whether providing the respondents with information about the negative impacts of air pollution on their health does affect their decisions of supporting pollution control efforts. The logistic function takes the following form:

$$\log C_i /(1 - C_i) = \beta_0 + \beta_i X_i + e \quad (4.2)$$

where β_0 is a constant.

In both regressions, the dependent variable is the Willingness to Support (WTS), which equals 1 if the respondent is willing to support the pollution control project, and 0 if the respondent is unwilling to support the project. The control variable is No-Info, which equals 1 if no information has been provided and the respondent is making his/her decision based on his/her own perception (subjective point of view) of the harm of pollution, and is 0 if the respondent has been provided with some facts about the negative consequences of air pollution on his/her health.

Table (5.4): The role of information in supporting pollution control projects

WTS	**Coef.**	**Odds Ratio**
No Info	-0.24**	0.67**
	(0.09)	(0.09)
Constant	0.70***	3.15***
	(0.05)	(0.26)
Number of Obs. = 1,051		
Log Likelihood = - 600.8		
Pseudo R^2 = 0.0054		
LR chi2 = 6.58	Prop > chi2 = 0.010	

Robust Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

The results shown in Table (5.4) emphasize that, as expected, the estimated coefficient of the variable for the lack of information is statistically significant and is negative, which means that people are less likely to support pollution control projects when they are not well informed about the negative consequences of air pollution on their health. In addition, the odds ratio is less than 1 for this variable, which indicates a negative association between lack of knowledge about the negative health effects of air pollution and the willingness to support pollution control projects.

As mentioned earlier, based on having a positive response to the initial dichotomous choice question, the respondents were asked whether they accept to pay a certain amount of money. Those respondents who answered "yes" were asked whether they would accept to pay a higher amount, and those who answered "no" were asked whether they would accept a lower amount. We have classified the respondents who were unwilling to support pollution control projects into two main categories: legitimate zero bidders and protest bidders, based on the reasons they provided for refusing to pay in principle. Those respondents who reported that low income is their main reason for not supporting pollution control projects were considered to have true zero WTP values, and the others were considered to be protest respondents, since they had some objection about who should really pay for air quality improvements, or had doubts about the feasibility of the project. Based on the above classification, 72 respondents (6.85%) were therefore considered to have a true zero WTP value, while 203 (19.3%) were considered to be protest responses. According to the study design, and in line with the standard practice in the vast majority of CV studies (e.g. Bateman & Brouwer, 2005), the protest responses were dropped off from the analysis[108].

Accordingly, in the next section we estimate the WTP for the two sub-samples using alternative Parametric and non- Parametric methods. In general, the Parametric approaches for estimating WTP measures from double-bounded dichotomous choice data are classified into two main categories. These are, either binary-response models which estimate the probability of a “yes” response as a function of bid values and selected covariates, or interval-data models which use the WTP intervals defined by bid values and responses as a dependent variable.

4.1.2. Sub-Sample (1): WTP for a 50% reduction in industrial $PM_{2.5}$ air pollution

The total number of responses in this sub-sample is 525 responses[109], divided into two approximately equal sub-groups. As mentioned earlier, in the first sub-group, no information has been given to the respondents about the impacts of air pollution on their health. In the second sub-group, the respondents have been provided with some facts about the health impacts of pollution, which means that they were well informed about these adverse impacts. The average percentage of households who are willing to support pollution control projects for the two groups included in this sub-sample is nearly 71% as illustrated in Figure (5.5). This percentage equals 74% within the informed group compared with 67.5% in the group where the respondents have not been provided with information about the health risks associated with air pollution. This significant difference between the two percentages can be attributed to the impact of information[110].

[108] Mitchell and Carson (1989) indicated that it is a common practice in the vast majority of CVM surveys, particularly those conducted for benefit-cost analysis, to identify and drop protest responses. Also, Loomis et al (2011) have found no statistically significant differences in the WTP between the different approaches for dealing with protest responses (whether including protests or dropping them).

[109] The number of valid responses is 525 out of 529 responses for these two groups.

[110] The result of t-test for the two sub-groups shows that the willing to support pollution control projects is higher by a statistically significant margin within the sub-group that is well-informed about the negative impacts of air pollution on their health, $p = 0.0037$.

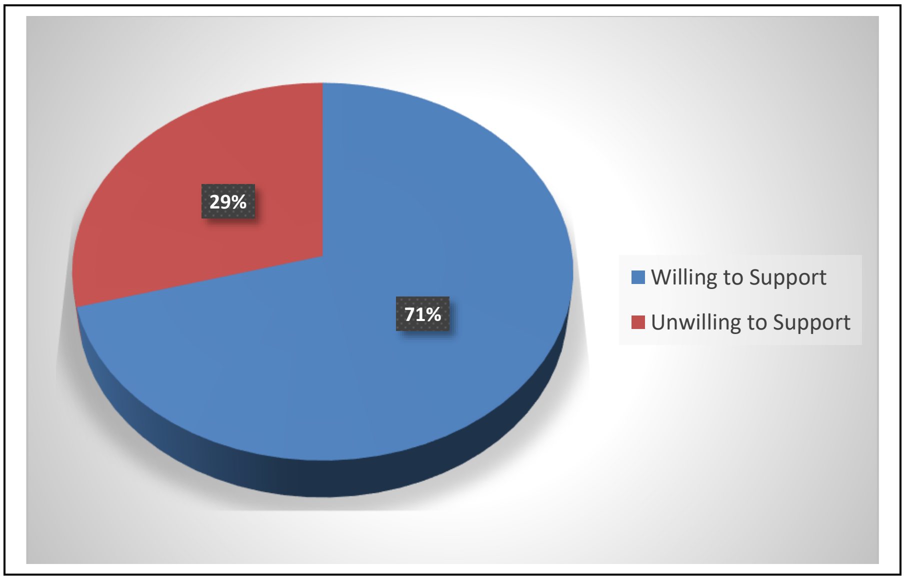

Figure (5.5): Willingness to support pollution control efforts in the first sub-sample

Table (5.5) provides a summary of the positive responses to the WTP questions within the whole sub-sample (the average of the two sub-groups). The reasons for unwilling to support pollution control projects are illustrated in Table (5.6). As shown in Figure (5.6), the main reasons for Egyptian households for not supporting pollution control efforts is their belief that it is the responsibility of the government, along with the polluters, to reduce pollution[111]. Also, low income seems to play a significant role in this regard, as nearly 25% of the participants have emphasized that their income is too low to afford paying for improving air quality.

The proportion of positive answers goes down as the bid amount goes up in the two sub-samples, as the percentages of "yes" responses equal nearly 88.6%, 72.9%, and 66.4% for bid amounts of 100LE, 200LE, and 300LE, respectively. Also, the results obtained from the estimation of a Bivariate Probit regression with the bid price as the only covariate, which has been conducted in order to test responses' consistency with economic theory, show that the initial bid variable is statistically significant with a negative sign, which indicates that the probability of a positive answer goes down as the bid goes up. On the other hand, the estimated coefficient of the follow-up bid has the expected negative sign, yet it is statistically insignificant. The value of ρ for this model is 0.33, which indicates a weak correlation between the response-generation functions (see Table (5A.2) in Appendix 5A).

[111] It is worth mentioning that when evaluating water quality, Jorgensen and Syme (2000) and Jones et al (2008) also has found that most protest responses were related to the belief that the government is the one who is responsible for improving water quality.

Table (5.5): Summary of the responses for the first sub-sample (average of groups (1) and (2))

Willingness to Pay for Improved Air Quality (reducing industrial $PM_{2.5}$ air pollution by 50%):

Total Sample Size: 529
“Yes” Responses: 374 (70.7%)

Starting Bid	100 LE (N = 123)				200 LE (N = 119)				300 LE (N = 132)			
First Response	Yes = 109 (88.6%)		No = 14 (11.4%)		Yes = 87 (73.1%)		No = 32 (26.9%)		Yes = 88 (66.7%)		No = 44 (33.3%)	
Second Bid	200 LE		50 LE		300 LE		100 LE		400 LE		200 LE	
Second Response	Yes = 72 (66%)	No = 37 (34%)	Yes = 10 (71.4%)	No = 4 (28.6%)	Yes = 53 (61%)	No = 34 (39%)	Yes = 16 (50%)	No = 16 (50%)	Yes = 59 (67%)	No = 29 (33%)	Yes = 18 (41%)	No = 26 (59%)
Follow up for “No-No” Response (open-ended)	(25, 20, 10, 35) **Mean = 22.5 LE**				(50, 50, 50, 50, 50, 50, 15, 30, 30, 20, 50, 50, 30, 50, 50, 20) **Mean = 40.3 LE**				(150, 50, 50, 100, 50, 75, 150, 50, 50, 50, 100, 40, 30, 100, 20, 100, 75, 40, 75, 50, 100, 50, 100, 50, 40, 100) **Mean = 70.96 LE**			

Table (5.6): Reasons for not supporting the projects in the first sub-sample

“No” Responses: 155 (29.3%)	
It is the government’s responsibility to reduce pollution	48
Polluters are the ones who should bear the cost	38
My income is too low to afford it	36
I don’t believe that the project will reduce air pollution	25
Other reasons	8
Total	155

Figure (5.6): Reasons for not supporting the projects in the first sub-sample

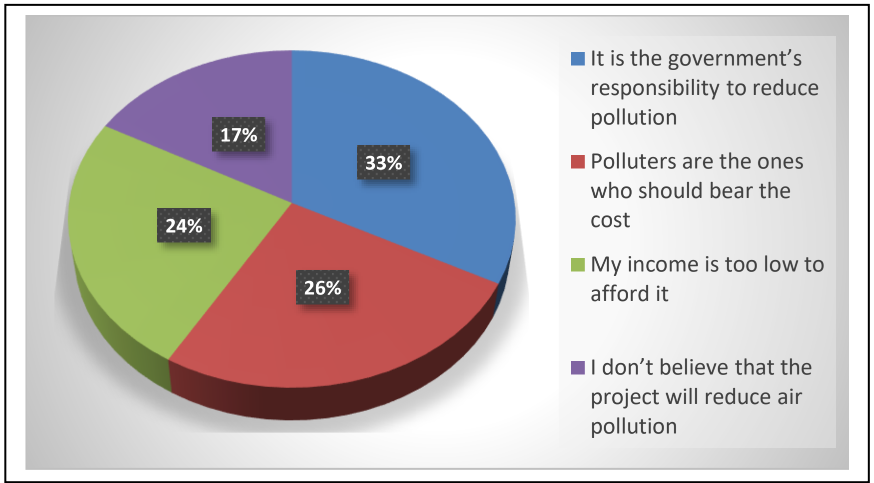

Figure (5.7) shows that the percentages of respondents who are willing to pay for reducing $PM_{2.5}$ air pollution caused by industrial activities by 50% within the informed group are larger than their counterparts in the group where the respondents have not been provided with information at all bid levels.

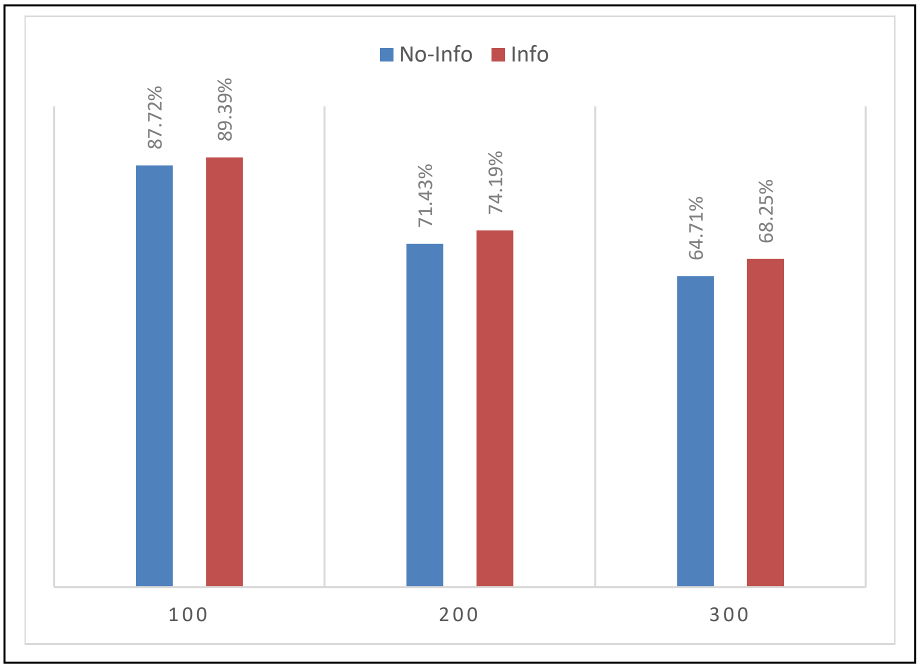

Figure (5.7): The percentages of respondents who have a positive WTP within the first sub-sample

We employ a Probit regression estimator in order to explore the factors affecting the willingness to support efforts for reducing $PM_{2.5}$ air pollution resulting from industrial activities and the marginal effects of these variables. The results are shown in Table (5A.3) in Appendix 5A. The results are similar to those obtained from the pooled sample, which again emphasizes the role that information can play in affecting Egyptian households' decisions on supporting the efforts for improving air quality. A detailed presentation of the socio-demographic characteristics of the households, which may affect their WTS for pollution control projects, and the amount they are willing to pay in order to reduce $PM_{2.5}$ air pollution, will be offered later in the discussion section of this chapter.

A wide variety of methods have been proposed in literature in order to estimate the WTP measures (mean and/or median), and in order to build the confidence intervals for these measures. In the next part, we estimate the WTP measures for a 50% reduction in $PM_{2.5}$ air pollution resulting from industrial activities using some of these methods. First, we employ the maximum-likelihood method for a standard double-bounded choice model as suggested by Hanemann et al (1991), or the so-called Interval-Data Model[112] (Haab and McConnell, 2002), for estimating the mean WTP with and without socio-demographic and attitudinal variables, where the WTP is estimated using the following formula (Lopez-Feldman, 2012):

$$WTP_i\,(z_i, u_i) = z_i\beta + u_i \tag{4.3}$$

In this linear function, z_i refers to the vector of explanatory variables including the bid variable. The vector of the parameters is represented by β, and u_i is the error term.

As shown in Table (5.7), estimating the model[113] with no covariates, yielded an estimated mean WTP for reducing industrial $PM_{2.5}$ ambient air pollution that is approximately equals to 309.8LE, with a standard error of nearly 11LE. An estimation of the WTP for the mean values using the Delta method after including some explanatory variables in the model is reported in Table (5.7) as well. The results also show that adding socio-demographic and attitudinal variables to the model slightly affects the amount of the WTP, where the estimate has decreased slightly to 301.8LE in this model, compared with the model where no control variables were included. The socio-demographic characteristics of the households which may affect the amount they are willing to pay in order to reduce $PM_{2.5}$ air pollution are shown in Table (5A.4) in Appendix 5A.

Table (5.7): WTP for improved air quality using the Interval data model

	WTP (bid only)	**WTP (covariates)**
Mean Value	309.8***	301.8***
	(11.17)	(10.5)
[95% Conf. Interval]	(287.9 – 331.7)	(281 – 322.4)
Number of Obs.	372	372

Robust Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

There is evidence that both the mean and the median WTP can be extremely sensitive to the assumptions embedded in the estimation procedure about the WTP distribution (Haab and McConnell, 2002). For example, if the distributions of the WTP implied by the first and follow-up responses are different, then

112 This model is a special case of the bivariate model where there is a perfect correlation between the response-generation functions.

113 Estimation results for the Interval Data Model (for the two versions; with and without control variables) have been obtained using the "doubleb" Stata module, which is designed to estimate the double-bounded dichotomous choice model for contingent valuation as proposed by Hanemann et al (1991) (Lopez-Feldman, 2012). This command directly calculates β, and when no control variables are included in the model the WTP is simply a constant. Meanwhile, after adding some explanatory variables to the model, an extra command is needed in order to estimate the WTP for the mean values, that is the "nlcom" command, which uses the Delta method in its calculations.

interval-data models may produce biased results. Also, in many cases the WTP is not normally distributed, which means that estimating the confidence interval for the welfare measures using the delta method may be inaccurate, as it would not reflect the skewness of the distribution of WTP.

Haab and McConnell (2002) and Hole (2006) indicated that when the WTP is asymmetrically distributed, then using the method developed by Krinsky and Robb (1986)[114] in constructing the confidence intervals may yield more accurate estimates than the delta method, as it does not require the assumption of a symmetrical WTP distribution. According to this method, a large number of draws[115] are randomly pulled out of a multivariate normal distribution, with the means given by the estimated coefficients, and covariances given by the estimated covariance matrix of the coefficients (Cooper, 1994; Hole, 2006). By estimating a WTP value for each draw using the regression equation, a simulated WTP distribution is generated, and the percentile confidence interval for the WTP can be estimated[116].

Therefore, the second double-bounded parametric model we employ in this analysis is the Bivariate Probit model as proposed by Cameron and Quiggin (1994), where the mean WTP and the 95% confidence intervals are estimated using the Krinsky and Robb method[117]. The estimated model takes the following form:

$$R_1 = \alpha_1 + \beta_i A_1 + \sum \beta x_i + u_1,$$

$$R_2 = \alpha_2 + \beta_i A_2 + \sum \beta x_i + u_2,$$

$$Corr[u_1, u_2] = \rho \qquad (4.4)$$

Where R_1 and R_2 refer to the binary WTP responses for the first and second bids, respectively. Both A_1 and A_2 indicate the first and the second bid prices, x_i represents the vector of the respondents' characteristics, and both β and α are the parameters to be estimated. Finally, ρ denotes the correlation between the error terms of the two equations. This correlation parameter measures the extent to which the responses to both the first and the follow-up bids are jointly determined. Alberini (1995b) indicted that if ρ equals one[118], which indicates a perfect correlation between the two WTP error terms, the interval-data

114 This method is also referred to as the parametric bootstrap.

115 In our adaptation, 5000 replications were generated for each WTP (Jeanty 2008).

116 An estimate of the 95% confidence interval is obtained by removing the highest and lowest 2.5% of the estimated values.

117 Estimation has been done using the STATA command "wtpcikr" which computes mean and/or median WTP, Krinsky and Robb confidence intervals, and relative efficiency measures such as achieved significance levels, works after estimation commands which should be probit, logit, and biprobit.

118 This restricted Bivariate Probit is equivalent to the interval model applied by Hanneman et al (1991).

model would be a more appropriate statistical tool to analyze the data. On the other hand, a zero value of ρ would imply no correlation between the error terms, which indicates that an estimation using a separate single-bounded model for each response could be appropriate as well. Finally, if the value of ρ is less than unity[119], the Bivariate Probit becomes the preferred statistical model (Alberini,1995b).

The results obtained from the Bivariate Probit regression, as shown in Table (5) in Appendix 5A, indicate that the correlation coefficient is statistically different from zero at a 5% significance level. In addition, the fact that ρ is less than unity implies that the correlation between the error terms of the first and follow up equations is not perfect. Also, the result of the Wald test for independence confirms the rejection of the null hypotheses that there is no correlation between the error terms of the two equations, which means that analyzing the data using the Bivariate Probit model instead of using two independent Probit equations could be more appropriate. The estimated mean/median WTP and the Krinsky and Robb (95%) confidence intervals for the WTP measures, as obtained from both the Bivariate Probit and Probit models, are shown in Table (5.8)[120]. The estimated mean/median WTP generated by the double-bounded model are similar to those produced by the single-bounded model. This similarity in magnitude of the single and double-bounded estimates confirms that the double-bounded elicitation format is not in itself a source of bias.

Table (5.8): Krinsky and Robb (95%) confidence intervals for the WTP measures in the first sub-sample

Model	**Measure (Mean/Median) WTP**	**Lower bound**	**Upper bound**	**CI/Mean**
Double-bounded	379	320	509	0.50
Single-bounded	378	323	501	0.47

Comparing confidence intervals around the WTP estimates, indicates that the confidence interval for the Interval-Data estimator is tighter than the one obtained from the Bivariate Probit model. Also, the lower ratio of the confidence interval to the mean WTP, indicates a higher efficiency of the estimates obtained by the Interval-Data estimator.

Deriving the WTP measures using the parametric approach requires some assumptions about the distribution of the data (Bishop & Heberlein, 1979; Hanemann, 1984), hence it may result in inconsistent

[119] If the correlation between the two WTP variables is low, then either interval-censored data models, such that a simple probit model can be estimated over the pooled survey responses (Hanneman et al., 1991; Alberini et al., 1997), or Bivariate Probit models (Cameron & Quiggin, 1994) could be used to estimate the parameters.

[120] We have estimated mean WTP using the delta method for the Bivariate probit model, the estimated WTP was found to be approximately 326 LE, with 95% confidence interval ranging between 199.5 LE and 452 LE. These are much lower than their counterparts obtained using Krinsky and Robb method which yielded a mean/median WTP equal to 379 LE, with a confidence interval of 320 LE and 509 LE.

estimates if the distribution is incorrectly specified. On the other hand, one advantage of non-parametric techniques is that they do not impose a distribution onto the data. However, these methods do not allow for the inclusion of socio-demographic characteristics, also they can yield inconsistent estimates depending on the sample size and on the maximum bid amount offered. In order to overcome the potential problem of distributional misspecification, we use the Turnbull estimator[121] in order to obtain a distribution-free lower bound mean estimate of the WTP for improved air quality. As reported in Table (5.9), the Turnbull lower bound WTP is 212 LE, with a variance equal to approximately 84 LE, and a standard error of 9.17 LE.

Table (5.9): Turnbull lower bound WTP for improved air quality

tj	**Nj**	**Tj**	**Fj**	**Nj***	**Tj***	**Fj***	**fj***	**Elb**	**V(Elb)**	**Eub**
0p			0.000			0.000		0.000		54.24
100p	14	123	0.114			0.271	0.271			
200	32	118	0.271	32.00	118.00	0.336	0.065	12.94	66.998	19.407
300	44	131	0.336	44.00	131.00	1.000	0.664	199.24	17.028	597.71
300+			1.000							
Total	243	525		243	525			212.175	84.026	671.355

Parameter Definition: **tj** is the bid amount, **Nj** is the number of no responses; (WTP=0) to bid tj, **Tj** is the total number offered bid/total number of respondents for bid tj, **Fj** = Nj/Tj, **fj*** = F_{j+1}-Fj.

It is worth mentioning that our estimates of the WTP for a 50 percent reduction in $PM_{2.5}$ air pollution resulting from industrial activities in both the Greater Cairo and Alexandria metropolitan areas are not very different from those obtained by Abou-Ali and Belhaj (2005), who have estimated the WTP for a 50% reduction in air pollution caused by road traffic in Cairo to be equivalent to 18.07$ (283 LE) and 15.9$ (294 LE), using benefit transfer methodology from Rabat-Salé (Morocco) to Cairo (Egypt), under both the logit model and the simplified parametric approach, respectively.

In fact, all estimation techniques and statistical estimators have their own advantages and limitations, it has been suggested that while non-parametric models can be used in examining the bid design, they cannot be considered as a replacement for the parametric approach in estimating the WTP (Duffield and Patterson, 1991). Alberini (1995b) emphasized that when making a choice between the double-bounded interval-data and bivariate models, there is always a trade-off between bias and efficiency of the WTP estimates, and that in terms of the efficiency the double-bound specification is generally superior to the bivariate model. In general, interpreting the WTP estimates needs to be done with caution, and policy makers should be aware of the estimation technique that has been used in extracting welfare measures,

[121] Based on the modified Kaplan-Meier-Turnbull method (Carson and Steinberg, 1990; Haab and McConnell, 2002).

and the assumptions associated with it. From policy making point of view, a more efficient estimator would be preferable as the observations needed to achieve a given performance is fewer compared with a less efficient one. In addition, the magnitude of variance for the estimated welfare measure is another important factor in choosing estimation techniques and statistical estimators, as the length of the confidence interval reflects the degree of certainty for the estimated welfare measure.

Although the vast majority of CV studies introduce a single representative WTP value, this seems to be difficult in the current case as exploring the economic value of air quality and the health risks associated with air pollution in Egypt is still in an early stage, and the information available in that respect is extremely limited. Moreover, the WTP estimates differ dramatically between models, and related studies are very scarce due to the short history of environmental research in Egypt, and therefore there is no obvious external source to which these results may be compared. Thus, it seems more appropriate that the results of the valuation conducted in this study should be offered as a range of values, where the estimate obtained from the double-bounded interval-data model would define the upper bound of this range, with a mean WTP estimate of 302 LE per month, and the lower bound of this range of values would be defined by the non-parametric model, which gives a mean monthly WTP of 212 LE[122].

4.1.3. Sub-Sample (2): WTP for reducing annual baseline mortality risk attributable to ambient $PM_{2.5}$ air pollution

The total number of responses in this sub-sample is 526 responses divided into two approximately equal sub-groups[123].

The percentage of households who are willing to support pollution control projects is nearly 77% in group (3) as illustrated in Figure (5.8), where the respondents within this sub-group have been offered a 10 in 10000 reduction in the annual baseline risk for mortality attributable to diseases related to $PM_{2.5}$ air pollution resulting from industrial activities. This percentage equals about 74% in group (4), where the risk level is reduced to 5 in 10000.

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[122] In order to test the impact of zero responses on the WTP estimates, we have estimated both the Probit and the Bivariate Probit models after including zero bidders in the sample. The results indicated that the WTP estimates have been moderately affected. The estimated WTP for reducing ambient $PM_{2.5}$ air pollution by 50% has decreased from 399 LE to 374 LE for the Probit model, and from 405.88 LE to 369.2 LE for the Bivariate Probit model, and both decreases were statistically significant (*p* value of 0.00).

[123] The number of valid responses is 525 out of 531 responses for these two groups.

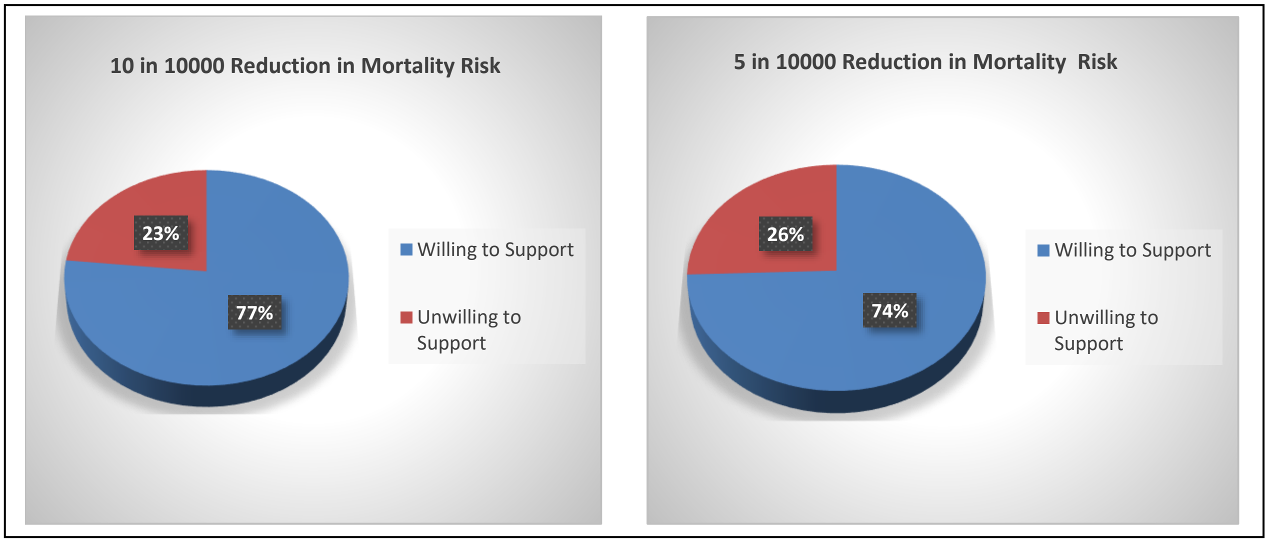


Figure (5.8): Willingness to support pollution control efforts in the second sub-sample

Table (5.10) introduces a summary of the positive responses to the WTP questions within the whole sub-sample (the average of the two sub-groups with two risk levels). A Kruksal-Wallis H test showed that there was a statistically significant difference in the WTS for pollution control projects between the two risk levels, as $\chi^2(1) = 4.673$, and $p = 0.0306$. The reasons for unwillingness to support pollution control projects in this sub-sample are listed in Table (5.11). As illustrated in Figure (5.9), the main reason for Egyptian households' unwillingness to support pollution control efforts for reducing the health risks is their belief that it is the responsibility of the government, along with the polluters, to reduce pollution. Also, low income seems to play a significant role in this regard, as nearly 21% of the participants have emphasized that their income is too low to afford supporting pollution control projects.

The proportion of positive answers goes down as the bid amount goes up in this sub-sample, as the percentages of "yes" responses equal nearly 92.4%, 71.2%, and 68.3% for the bid amounts of 100LE, 200LE, and 300LE, respectively. Also, the results obtained from the estimation of a Bivariate Probit regression, which has been conducted in order to test responses' consistency with economic theory, show that both bid variables are statistically significant with a negative sign, which indicates that the probability of a positive answer goes down as the bid goes up, as noted earlier. The value of ρ for the pooled sample in this model is 0.41, which indicates a weak correlation between the response generation functions (see Table (5A.6) in Appendix 5A).

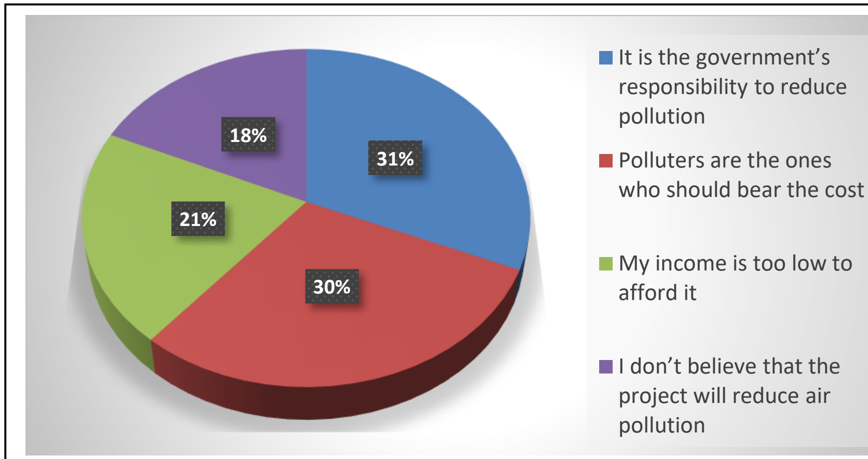
Table (5.10): Summary of the responses for the second sub-sample (average of groups (3) and (4))

Willingness to Pay for Health risk reduction (reducing annual baseline mortality risk attributable to $PM_{2.5}$ air pollution): **Total Sample Size: 531** **"Yes" Responses: 407 (76.65%)**												
Starting Bid	100 LE (N =133)				200 LE (N = 147)				300 LE (N = 127)			
First Response	Yes = 123 (92.5%)		No = 10 (7.5%)		Yes = 105 (71.4%)		No = 42 (28.6%)		Yes = 87 (68.5%)		No = 40 (31.5%)	
Second Bid	200 LE		50 LE		300 LE		100 LE		400 LE		200 LE	
Second Response	Yes = 78 (63.4%)	No = 45 (36.6%)	Yes = 5 (50%)	No = 5 (50%)	Yes = 68 (64.7%)	No = 37 (35.3%)	Yes = 24 (57%)	No = 18 (43%)	Yes = 51 (58.6%)	No = 36 (41.4%)	Yes = 13 (32.5%)	No = 27 (67.5%)
Follow up for "No-No" Response (open-ended)	(49, 10, 30,20,40) **Mean = 29.8 LE**				(75, 50, 50, 50, 20, 50, 50, 15, 5, 22, 50, 1, 50, 50, 20, 75,50, 30) **Mean = 39.6 LE**				(100, 50, 100, 100, 100, 50, 100, 100, 50, 199, 100, 18,10, 50, 0, 150, 100, 50, 50, 100, 150, 50, 50, 75, 100, 20, 150) **Mean = 80.4 LE**			

Table (5.11): Reasons for not supporting the projects in the second sub-sample

"No" Responses: 124 (23.35%)	
It is the government's responsibility to reduce pollution	38
Polluters are the ones who should bear the cost	36
My income is too low to afford it	25
I don't believe that the project will reduce air pollution	22
Other reasons	3
Total	124

Figure (5.9): Reasons for not supporting the projects in the second sub-sample



The results of the Probit regression are shown in Table (5A.7) in Appendix 5A, where we explore the factors affecting the willingness to support efforts for reducing mortality risks linked to industrial $PM_{2.5}$ air pollution, and the marginal effects of each of them. The results are similar to those obtained from the pooled sample, and they also emphasize the role that the level of health risk reduction can play in affecting the Egyptian households' decisions on supporting pollution control projects.

In this part, we test the validity of the WTP responses in the two sub-groups of this second scenario. First, we apply some tests of sensitivity to the magnitude of risk reduction. As illustrated in Figure (5.10), the proportion of positive answers goes down as the bid amount goes up in the two sub-groups. The percentages of respondents who are willing to pay for the 10 in 10000 risk reduction are larger than those for the 5 in 10000 risk reduction at all bid levels, as the percentages of "yes" responses for the smaller risk reduction are approximately equal to 91.4%, 68.3%, and 67.2 % compared with 93.2%, 75%, and 69.2% for the larger risk reduction, for the bid amounts of 100LE, 200LE, and 300LE, respectively.

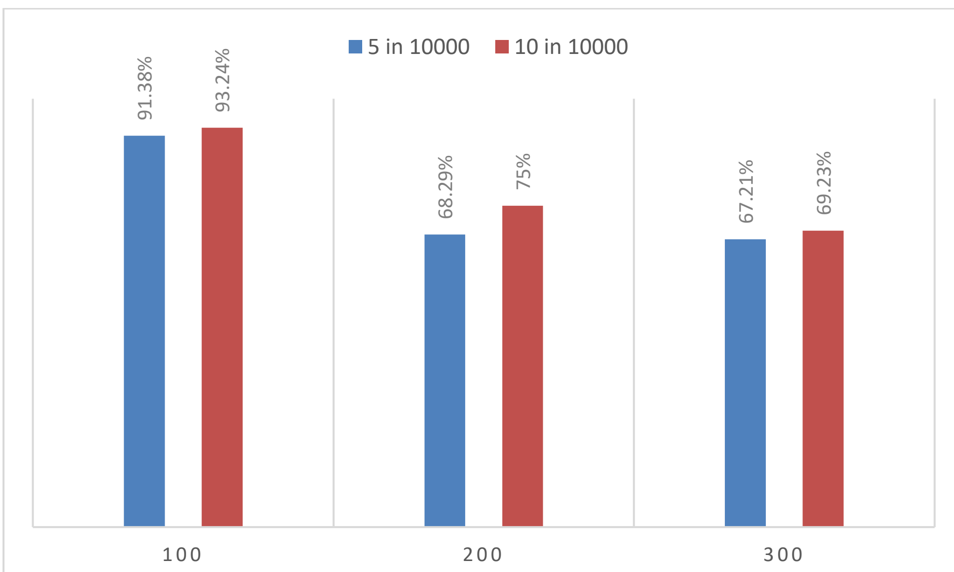


Figure (5.10): The percentages of respondents who have a positive WTP for the two risk levels

From some theoretical perspective, the WTP should increase with the magnitude of risk reduction, and this assumption has been frequently used as an indicator of validity in VSL studies, as failing to satisfy this condition may raise doubts about the validity of the results[124]. Also, WTP should increase in

[124] Therefore, the NOAA panel has recommended to test for scope sensitivity (Arrow et al., 1993). Scope sensitivity tests can be classified into two main categories: internal and external. An external test involves using independent sub-samples (which must be statistically equivalent) of respondents who are asked to place a value on different levels of a good (different scopes), while an internal test involves asking the same respondents to value the different levels of good. Within the CV literature, many studies have investigated the scope sensitivity hypothesis and various tests have been suggested (Bateman & Brouwer, 2005; Heberlein et al., 2005; Poe et al., 2005; Sund, 2009; Desvousges et al.,

proportion to the size of the risk reduction. Hammitt and Graham (1999), Hammitt (2000), Corso et al (2001), and Alberini et al (2004) have discussed a number of possible reasons for the occurrence of scope effect in CV studies on health risk reductions, either the "weak scope" which occur when WTP fails to increase with the sizes of the risk reduction, or the "strong scope" in case the proportionality requirement is not satisfied. They indicated that respondents may not be sensitive to variation in risk magnitude due to their lack of understanding of the numerical differences in magnitude and probabilities. Also, respondents may base their values on their prior knowledge or background information and not on the information provided in the scenario description. They also emphasized that strong sensitivity is often rejected in the empirical literature on risk reduction, while there is often support for weak sensitivity[125].

We use alternative parametric and non-parametric methods in order to estimate the WTP for a reduction in the annual baseline risk for mortality attributable to air pollution-related diseases. Table (5.12) shows the results obtained from the interval-data model for both risk reduction levels.

Table (5.12): WTP for mortality risk reduction using the Interval data model

	10 in 10000 risk reduction		**5 in 10000 risk reduction**	
	WTP (bid only)	WTP (covariates)	WTP (bid only)	WTP (covariates)
Mean Value	312.6***	317.6***	292.6***	293***
	(13.6)	(13)	(15.2)	(14)
[95% Conf. Interval]	(285.9 – 339.3)	(291.5 – 342.8)	(262.8 – 322.3)	(265.4 – 320.6)
Number of Obs.	203	203	201	201

Robust Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

In this regression, the estimated WTP for reducing the annual mortality risk by 5 in 10000 (the smaller risk reduction) is approximately equal to 292.6 LE, meanwhile it equals 312.6 LE for the larger risk reduction (10 in 10000). Including some control variables in the model only slightly affects the amount of the WTP. For the smaller risk reduction, the estimated WTP values under both specifications are nearly equal, and the WTP estimate for the larger risk reduction increases slightly, from 312.6 LE to 317.6 LE.

2012; Whitehead, 2016; Lopes & Kipperberg, 2020). However, many efforts have been recently devoted to identifying the conditions that may lead to scope insensitivity. Also, another perspective has emerged which suggests that the inability to pass the statistical scope test does not necessarily imply the invalidity of the CV exercise, and that the reasons behind such inability may be consistent with economic theory (Heberlein et al., 2005; Desvousges et al., 2012; Whitehead, 2016).

[125] In order to test the scope insensitivity hypothesis that the mean WTP is not significantly different between the two health risk levels. We have conducted a statistical scope test by separately eliciting both the $WTP_{5\ in\ 10000}$ and $WTP_{1\ in\ 1000}$ and testing whether the $WTP_{1\ in\ 1000} > WTP_{5\ in\ 10000}$ under the null hypothesis of insensitivity to scope. The hypothesis that the WTP is insensitive to the magnitude of risk reduction (the weak test) can be rejected (*p* value of 0.0258).

In order to account for the potential problem of distributional misspecification, we use the Turnbull estimator to obtain a distribution-free lower bound mean estimate of the WTP for reducing the mortality risk associated with air pollution.

Table (5.13): Turnbull lower bound WTP for a 5 in 10000 reduction in mortality risk

tj	Nj	Tj	Fj	Nj*	Tj*	Fj*	fj*	Elb	V(Elb)	Eub
0p			0.000			0.000		0.000		63.415
100p	5	58	0.086							
200	26	82	0.317	26.00	82.00	0.317	0.317	2.159	105.63	3.239
300	20	61	0.328	20.00	61.00	0.328	0.011	201.64	36.126	604.92
300+			1.000			1.000	0.672			
Total	119	269		119	269			203.798	141.755	671.571

Parameter Definition: **tj** is the bid amount, **Nj** is the number of no responses; (WTP=0) to bid tj, **Tj** is the total number offered bid/total number of respondents for bid tj, **Fj** = Nj/Tj, **fj*** = F_{j+1}-Fj.

As shown in Table (5.13), the Turnbull lower bound WTP for the 5 in 10000 reduction in mortality risk is 203.8 LE, with a variance equal to approximately 141.8 LE, and a standard error of 11.9 LE.

Table (5.14): Turnbull lower bound WTP for a 10 in 10000 reduction in mortality risk

tj	Nj	Tj	Fj	Nj*	Tj*	Fj*	fj*	Elb	V(Elb)	Eub
0p			0.000			0.000		0		50
100p	5	74	0.068							
200	16	64	0.25	16.00	64.00	0.250	0.25	11.538	117.188	17.308
300	20	65	0.308	20.00	65.00	0.308	0.058	207.692	32.772	623.077
300+			1.000			1.000	0.692			
Total	95	257		95	257			219.231	149.959	690.385

Parameter Definition: **tj** is the bid amount, **Nj** is the number of no responses; (WTP=0) to bid tj, **Tj** is the total number offered bid/total number of respondents for bid tj, **Fj** = Nj/Tj, **fj*** = F_{j+1}-Fj.

Also, as shown in Table (5.14) the Turnbull lower bound WTP for the 10 in 10000 reduction in mortality risk is 219 LE, with a variance equal to approximately 150 LE, and a standard error of 12.24 LE. As mentioned earlier, due to the lack of studies on the VSL in Egypt, the results of the valuation conducted in this study are given as a range of values, where the estimates obtained from the double-bounded interval-data model define the upper bound of this range, with mean WTP estimates of 293 LE, and 317.6 LE per month, for the 5 in 10000 and the 10 in 10000 mortality risk reductions, respectively. The lower bound of this range of values is defined by the non-parametric model, which gives a mean monthly WTP of 203.8 LE, and 219 LE, for the 5 in 10000 and the 10 in 10000 mortality risk reductions, respectively.

As mentioned earlier, according to theory the WTP should increase proportionally to the size of the risk reduction. However, this has not been found to be true in the vast majority of empirical literature. In our sample, the WTP for the annual mortality risk reduction by 10 in 10000 is only 1.07 times the WTP for the smaller risk reduction of 5 in 10000, which is lower than those found in other studies, that used the same annual mortality risk reductions, as this percentage ranged from 1.15 for Mongolia to 1.6 in the USA (Alberini et al., 2004; Hoffmann et al., 2012).

The economic value of health risk reduction, or the VSL, can be calculated based on both the WTP to avoid premature mortality due to air pollution and the percentage of change in risk, *r*, according to the formula:

$$VSL = \frac{WTP}{\Delta r} \quad (4.5)$$

Table (5.15) illustrates the VSL for both the upper and lower bounded WTP estimates for reducing the base line mortality risk attributable to ambient $PM_{2.5}$ air pollution.

Table (5.15): The VSL estimations using Parametric and Non-Parametric methods[126]

Method	10 in 10000 risk reduction	5 in 10000 risk reduction
Parametric	3,811,200 LE (242.724 $)	7,032,000 LE (447.847 $)
Non-Parametric	2,628,000 LE (167.369 $)	4,891,200 LE (311.506 $)

The derived VSL is higher for the smaller risk reduction because the estimated WTP is less than proportionate to the risk reduction. The VSL estimates range from about 3.81 million LE for the larger risk reduction to nearly 7.0 million LE for the smaller risk reduction. It is worth mentioning that a recent study by the World Bank (2019) have used the benefit transfer method for valuing the mortality due to environmental health risks in Egypt, drawing on the empirical literature of VSL in the OECD countries. According to this approach the estimated VSL in Egypt was found to be LE 3.0 million in the year 2016/2017.

Finally, comparing the WTP for the two sub-samples, i.e. for improved air quality and for mortality risk reduction, in both Greater Cairo and in Alexandria, shows that the estimated coefficient of the variable indicating residency is statistically significant and is positive, which indicates that people living in the

[126] Since the WTP is estimated on per month basis, the VSL is calculated as follows: VSL = (WTP * 12)/ Δr.

Greater Cairo metropolitan area are more likely to be willing to pay additional amounts of money for improving air quality and for reducing the health risk associated with air pollution, compared with Alexandria's residents (see Tables (5A.9) and (5A.10) in Appendix 5A). In addition, a Kruksal-Wallis H test showed that there was a statistically significant difference in the WTS for pollution control projects between the residents of Greater Cairo and Alexandria, as $\chi^2(1) = 14.502$, $p = 0.0001$ for the health risk reduction group, and $\chi^2(1) = 16.452$, $p = 0.0001$ for the improved air quality group.

Table (5.16): The WTP for improved air quality and for mortality risk reduction in Greater Cairo and in Alexandria using the Interval data model

	Improved Air Quality		Mortality Risk Reduction			
			10 in 10000		5 in 10000	
	Cairo	Alexandria	Cairo	Alexandria	Cairo	Alexandria
WTP Mean Value	329.7*** (13.7)	263*** (18.4)	326.8*** (16.55)	277.7*** (22.39)	324*** (19.8)	220*** (20.5)
[95% Conf. Interval]	(303 – 356.5)	(227 – 299)	(294 – 359)	(234 – 322)	(285 – 363)	(180 – 260.5)
Number of Obs.	257	115	139	64	145	56

Robust Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

As shown in Table (5.16), the estimated WTP for reducing $PM_{2.5}$ air pollution resulting from industrial activities by 50% in Greater Cairo (329.7 LE per month) is significantly higher than its counterpart in Alexandria (263 LE per month). Meanwhile, the estimated WTP for reducing the baseline mortality risk associated with industrial $PM_{2.5}$ air pollution in Greater Cairo is also significantly higher than its counterpart in Alexandria. The WTP estimates for the 5 in 10000 mortality risk reduction in Greater Cairo is about 324 LE, compared with 220 LE in Alexandria. For the larger risk reduction of 10 in 10000, the residents of Greater Cairo have a mean WTP of nearly 327 LE per month, while Alexandria's residents have a WTP of only about 278 LE per month. According to the above, the estimated figures of the VSL in Greater Cairo are much higher than their counterparts in Alexandria, where they range between 3,921,600 LE and 7,776,000 LE in Greater Cairo (249.755 $ and 495.230 $), while in Alexandria they are estimated to range between 3,332,400 LE and 5,280,000 LE (212.230 $ and 336267 $), for the 10 in 10000 and the 5 in 10000 mortality risk reductions, respectively.

5. Discussion

Qualitative analysis of the survey responses shows that a large portion of Egyptian households are suffering from pollution related diseases, and that they also seem to have a low level of environmental awareness. Nevertheless, an average of nearly 70% out of the 1051 households surveyed were positive towards supporting efforts to improve air quality at both study sites. This indicates that although Egypt is among the lower-middle income countries and that it doesn't have a specific budget allocated for improving air quality, a high percentage of Egyptian households are willing to pay for reducing the air pollution load. The results also show that the main reason for households not to support pollution control projects[127] is their belief that the government, along with the polluters, are responsible for controlling pollution. Low income is also a significant reason for unwillingness to support pollution control projects for respondents who are females, residents of Greater Cairo, or among the younger ages (for about 30% of them). Our results also indicate that air in Greater Cairo is perceived to be more polluted and to be causing greater health concerns compared with Alexandria[128]. That is reflected in the higher estimated figures of both the WTP for improved air quality and the VSL in Greater Cairo compared with their counterparts in Alexandria.

Literature and studies on valuing air quality and the health risks associated with air pollution in Egypt are very scarce. Thus, there is a lack of external references to which our results can be compared. Therefore, our results are offered as a range of values, with the estimates obtained from the double-bounded interval-data model defining the upper bound of this range, and the estimates obtained from the non-parametric model defining its lower bound. Our results suggest that the mean WTP estimate for reducing $PM_{2.5}$ air pollution resulting from industrial activities ranges between 212 LE and 302 LE per month (13.5US$ and 19.3US$). In quantifying the benefits of policies aiming at saving lives through mortality risk reduction, our results suggest that the WTP ranges between 203.8 LE and 293 LE per month (13.35US$ and 18.7US$) for the 5 in 10000 mortality risk reduction, and ranges between 219 LE and 317.6 LE per month (US$ 14 and 20.3US$), for the 10 in 10000 mortality risk reduction. Accordingly, the VSL estimates range from about 3.81 million LE for the larger risk reduction to nearly 7.0 million LE for the smaller risk reduction[129].

[127] The number of protest responses is 203 (about 19.3% of the sample size).

[128] The subsamples are similar, with no significant differences in means (two-sample t-test, $p < 0.05$).

[129] The vast majority of CV studies have found the strong scope hypothesis to be rejected, as they usually obtained WTP values which vary less than proportionately to the risk reduction. Therefore, the derived VSL estimates for large risk reductions are usually smaller than those for a small risk reduction (Jones-Lee et al., 1985; Corso et al., 2001; Krupnick et al., 2002; Liu et al., 2003; Ortiz et al., 2009; Hole et al., 2016).

Although "information" plays a crucial role in CV surveys as emphasized by many studies (e.g. Bergsrtom et al., 1990; Carlsson and Johansson-Stenman, 2000; Venkatachalam, 2000), mixed results have been found regarding the impact of information on the WTP[130]. We have found that the information provided in the CV scenarios does affect the WTP values, as providing the respondents with additional information about the adverse health impacts of air pollution has significantly influenced their willingness to support pollution control projects and their WTP values. Furthermore, the estimated WTP for improved air quality of the respondents who were well informed about the negative consequences of air pollution on their health was found to be higher than that of the respondents who were not provided with the same information. These results are similar to those of Istamto et al (2014), who also found that people who are well aware of the health effects of industrial air pollution do have a higher WTP.

The level of mortality risk reduction has been found to be a significant predictor of the respondents' WTP, since the variable indicating risk level was found to be significant and positively related to the respondents' WTP. With respect to scale sensitivity, our results only satisfy the expression of "weak scope", as we have found that the respondents' WTP increases with the level of risk reduction, while they don't satisfy the condition for "strong scope", which requires that the increase in the WTP should be proportional to the level of risk reduction[131]. However, the mean WTP of respondents faced with the larger risk change has been found to be significantly greater than the mean WTP of the respondents faced with the smaller risk change. Regarding risk perceptions, our results suggest that water pollution and traffic accidents are subjectively perceived by Egyptian households to be more serious sources of health risks than air pollution.

The results indicate that, in general, the estimated WTP values are likely to be higher for those with higher incomes. However, this generally positive relationship between the WTP and wealth has not been found to be consistent across all levels of income. This can be explained by the differences between people in their attitudes towards risk, which may vary in such a way as to offset an income effect. It is worth noting that when valuing environmental goods such as clean air, it is expected that the WTP should represent only a small portion of the respondent's income, and therefore respondents who have expressed

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[130] Bergsrtom et al (1990) Indicated that the influence of the additional information on the WTP value depends to a great extent on the level of information possessed by the individuals.

[131] The lack of strong scope effect might reflect the Egyptian households' unfamiliarity with health risks valuation and the difficulties they have in understanding risk information, also it might reveal respondents' preference for seeing some form of policy action.

high WTP relative to their income might have failed to consider their budget constraints, have intentionally misreported their income, or have miscalculated it[132].

Our study provides some evidence of a positive relationship between age and the VSL, as we have found that the WTP for mortality risk reduction is significantly lower among the older respondents. Regarding the impact of health status on the WTP, our result suggests that people with severe health conditions, such as cancer, are willing to pay less than other individuals for reductions in the risk of dying. We also found that people are willing to pay more for the risk reduction if they are in a good health status. These findings are contrary to those of Alberini et al (2006), who found that people who have cancer are willing to pay more in order to reduce the risk of cancer-related deaths

A positive relationship between educational level and the WTP has not been found to be consistent across all levels of education. Nevertheless, a negative relationship between the WTP and education might also be anticipated in some cases, in particular when there are reasons to doubt the merits or the benefits associated with a specific pollution control project, as highly educated respondents such as those with postgraduate qualifications are more likely to be familiar with such reasons.

Our results indicate the internal validity of the survey responses, as the WTP relates well to households' economic circumstances. We found that certain segments of the sample were significantly more willing to pay for improved air quality and for mortality risk reduction compared to others, such as those who are females, those at a younger age (24-39 years old), people living in the more polluted areas, those who have children, and those who are already applying some protective measures.

Study Limitations

We have had to struggle with a variety of problems in conducting this research in Egypt. First, internet users represent only about 59% of the Egyptian population, and also the illiteracy rate is very high in Egypt as it includes nearly 29% of the population. In addition, almost 29.7% of the population in Egypt live under the national poverty line (CAPMAS). Therefore, the main limitation concerns the generality of the results, as the respondents recruited within this sample were more likely to be educated, and to belong to the middle-income class of the population, and it is possible that another sample with different

[132] The number of households who reported a WTP that is more than 5% of their income is about 103, which represents about 9.8% of the total sample size.

demographic characteristics could yield different findings. It can be said that this sample is not reflective of the general population, as might be desirable by policymakers, as these results are only limited to internet users. In addition, the values of the WTP and the VSL estimated in this study should be understood to be mostly meaningful for urban areas, and not the outlying rural areas of Egypt, where although it is possible that air pollution is less serious.

The second problem is unfamiliarity with survey methodology among the general Egyptian population due to their low exposure to surveys, in addition to the low levels of environmental awareness within Egyptian households. Another problem involves the unfamiliarity with the valuation task, particularly when valuing health risks, and especially for low probability illnesses, because of the apparent difficulties people have in understanding risk information.

Despite these difficulties we faced during this valuation study, we believe that our results can provide valuable information to policymakers and practitioners seeking to evaluate the benefits of an intervention in order to improve environmental health outcomes in urban settings, also this study could be helpful for future developments of CVM studies in developing countries in general, and in Egypt in particular.

6. Summary and Concluding Remarks

Egypt's economic development and industrialization policies, combined with weak environmental management, and lack of environmental policies, especially those focused on reducing emissions, have resulted in a widespread and severe air pollution, particularly in Greater Cairo and in Alexandria, which are the largest and the most populous metropolitan areas in the country. Evidence from the literature on epidemiology confirms the substantial link between exposure to air pollution and the occurrence of higher mortality and morbidity rates from respiratory and cardiovascular diseases, along with certain types of cancers, which suggests that policies aiming to reduce air pollution and those aiming to avoid premature mortality and morbidity can potentially yield significant social welfare gains. Estimating the economic value of improving air quality and the health benefits associated with it are key inputs into the estimation of the benefits and costs of air pollution mitigation strategies and policies, which may enhance individuals' probability of survival.

The present work aims at estimating the economic value of improved air quality (or the implicit shadow price of air quality) and the value of mortality risk reduction in Egypt. We used a CV survey instrument in order to estimate the WTP for improved air quality and for reducing the mortality risk associated with air pollution, in both the Greater Cairo and Alexandria metropolitan areas. To the best of our knowledge, the economic value of the reduction in mortality risk attributed to air pollution has never been evaluated for Egypt using CVM before. This work presents an attempt to fill this gap, given the seriousness of air pollution in Egypt, especially in Greater Cairo and in Alexandria, where more than 80 percent of the country's industrial activities take place. In light of this, one of the main objectives of this study is to estimate the WTP measures for both improved air quality, and for a reduction in the risk of premature mortality due to air pollution, and consequently estimate the corresponding VSL. Another purpose is to examine the impact of information on Egyptian households' decisions for supporting pollution control efforts. Also, we aim at examining urban Egyptians' perception and awareness of air pollution and its related health impacts. In addition, this study examines the associations between the WTP and households' socio-economic characteristics and explores the feasibility of the application of CV surveys in Egypt.

An Internet-based survey was conducted in Arabic, and administered through the online survey research software Qualtrics, for 1060 households which have been chosen using the quota sampling technique. The survey was conducted during the period between November 2020 and February 2021.The survey consisted of seven sections, where we have collected socio-demographic information, information on the public perception of air quality and awareness of air pollution and its health-related impacts, in addition to information on attitudes towards environmental protection. We used a double-bounded dichotomous choice question format in order to elicit the WTP for both an improved air quality and a reduction in the mortality risk associated with air pollution, using an increase in the general sales tax as a payment vehicle. Respondents have been randomly assigned to one out of two scenarios. In the first scenario the respondents have been asked about their willingness to support a pollution control project that aims at reducing $PM_{2.5}$ air pollution resulting from industrial activities by 50%. Two versions of this scenario, with and without providing information about the problem of air pollution and its impacts on health, have been provided to the respondents in order to examine the effect of information across different households. In the second scenario, the respondents have been asked about their willingness to support a project that will reduce the baseline mortality risk due to exposure to $PM_{2.5}$ industrial air pollution. The risk reduction scenario includes two levels of annual mortality risk reductions, 5 in 10000 and 10 in 10000 per year over the following 10 years.

Survey responses have been analysed using several statistical methods in order to check the consistency of survey responses with economic theory, to explore the factors affecting households' decisions on supporting pollution control projects, with a special focus on the role that information can play in this regard, to estimate the WTP for both improved air quality and health risk reduction, to check the robustness of the WTP estimates to different approaches, to test for response sensitivity to the scope of the risk reduction, and finally to check the internal validity[133] of the WTP responses. To achieve these aims, we have used a parametric approach which assumes some particular distribution for the WTP. Within this framework, we have used both the interval data model and the bivariate probit model, such as to find the one which provides the better fit for the data. In addition, we have also used the Turnbull nonparametric modification of the Kaplan-Meier estimator, which makes no assumptions about the shape of the underlying WTP distribution. Our results from both the parametric and non-parametric approaches highlight the importance of careful statistical analysis of data gained from CV surveys.

The qualitative analysis of the survey responses shows that more than 70% out of the 1051 households surveyed were positive towards supporting efforts to improve air quality at both study sites. The results also indicate that a large portion of Egyptian households suffer from pollution related diseases, and that they also seem to have a low level of environmental awareness. Our results suggest that the mean WTP estimate for reducing $PM_{2.5}$ air pollution resulting from industrial activities within Egyptian households ranges between 212 LE and 302 LE per month (13.5US$ and 19.3US$). In quantifying the benefits of policies aiming at saving lives through mortality risk reduction, our results suggest that the VSL estimates in Egypt range between about 3.81 million LE to nearly 7.0 million LE. Low income is a significant reason for about 6.5% of the respondents for their unwilling to support pollution control projects, while the belief that the government, along with the polluters, are responsible for controlling pollution were the main reasons for not supporting pollution control projects for about 19.5% of the respondents. Air in Greater Cairo is perceived to be more polluted and to be causing greater health concerns compared with Alexandria. This is reflected in the higher estimated figures of both the WTP for improved air quality and the VSL in Greater Cairo, compared with their counterparts in Alexandria.

Regarding factors affecting the WTS pollution control projects and the WTP values, it has been found that providing the respondents with additional information about the adverse health impacts of air pollution has significantly increased their willingness to support pollution control projects and their WTP values. Also, the level of mortality risk reduction has been found to be a significant predictor of the respondents' WTP. Regarding the socio-demographic factors that may have an influence on the WTP values, the results indicate that, in general, the estimated WTP values are likely to be higher for those with higher incomes. A positive relationship between educational level and the WTP has not been found to be consistent across all levels of education. Our study provides some evidence of a positive relationship between age and the VSL, as we have found that the WTP for mortality risk reduction is significantly lower among the older

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[133] Understanding the way the WTP is influenced by different factors is important not only for validity testing, but also for examining the way these values may differ among socio-economic or demographic groups.

respondents. Regarding the impact of health status on the WTP, our result suggests that people with severe health conditions, such as cancer, are willing to pay less than other individuals for reductions in the risk of dying. We also found that people are willing to pay more for risk reduction if they are in a good health status. We found that certain segments of the sample were significantly more willing to pay for improved air quality and for mortality risk reduction compared to others, particularly females, those of younger age (24-39 years old), people living in the more polluted areas, those who have children, and those who are already applying some protective measures.

In general, it can be said that assigning monetary values for improving air quality and for the reduction in health risks associated with air pollution can provide policy makers with valuable information for analysing the relevant costs and benefits of policy interventions, and it also helps in avoiding the uncertainties of benefit transfer methods, which represent the only alternative to fill the gaps in the availability of information on the preferences of individuals in Egypt. This study has shown that most residents of the Greater Cairo and Alexandria metropolitan areas are willing to pay in order to avoid regularly experiencing air pollution levels known to harm health and to increase the risk of early death. This result should encourage implementing effective policies such as to reduce industrial air pollution levels in urban settings in Egypt, which can possibly generate substantial health and economic gains. Also, spreading awareness of air pollution and the associated health risks to the overall population would play a key role in supporting environmental protection efforts.

Appendix (5A): Estimation Results

Table (5A.1): Testing the consistency of the responses with economic theory in the pooled sample: a Bivariate Probit model with only bid prices as covariates.

	Coef.	[95% Conf. Interval]	
Answer 1			
Bid 1	-0.004***	-0.005	-0.003
	(0.000)		
Constant	1.54***	1.25	1.82
	(0.146)		
Answer 2			
Bid 2	-0.002**	-0.003	-0.000
	(0.000)		
Constant	0.623***	0.253	0.993
	(0.188)		
Rho	0.37	0.163	0.545
	(0.098)		
Number of Obs. = 776			
Log Likelihood = 919.27			
Wald chi2 = 38.5		Prop > chi2 = 0.000	
LR test of Rho = 0	chi2 = 13.05	Prop > chi2 = 0.000	

Robust Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

Table (5A.2): Testing the consistency of the responses with economic theory in the first sub-sample: a Bivariate Probit model with only bid prices as covariates.

	Coef.	[95% Conf. Interval]	
Answer 1			
Bid 1	-0.003***	-0.005	-0.002
	(0.000)		
Constant	1.45***	1.05	1.86
	(0.206)		
Answer 2			
Bid 2	-0.001	-0.003	0.000
	(0.000)		
Constant	0.568**	0.042	1.09
	(0.268)		
Rho	0.33	0.033	0.575
	(0.14)		
Number of Obs. = 372			
Log Likelihood = 443.54			
Wald chi2 = 16.5		Prop > chi2 = 0.000	
LR test of Rho = 0	chi2 = 5.19	Prop > chi2 = 0.022	

Robust Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

Table (5A.3): Factors affecting the WTS pollution control projects in the first sub-sample

WTS	Coef.	[95% Conf. Interval]		Marginal Effects
Information	0.42*** (0.129)	0.17	0.67	0 .124*** (0.037)
Gender	-0.03 (0.16)	-0.34	0.28	-0.008 (0.047)
Residency	0.40*** (0.13)	-0.14	0.66	0.117*** (0.038)
Age Group (1)	0.44*** (0.14)	0.17	0.71	0.129*** (0.039)
Age Group (3)	-1.27*** (0.256)	-1.77	-0.76	-0.374*** (0.07)
Years of Schooling	0.107* (0.06)	-0.004	0.22	0.0313** (0.016)
Low Income	-0.19 (0.18)	-0.55	0.17	0.056 (0.054)
High Income	0.29* (0.15)	-0.01	0.59	0.086** (0.045)
Lung Cancer	-1.07** (0.48)	0.12	2.02	0.315** (0.141)
Job type	0.34* (0.175)	-0.007	0.68	0.099** (0.051)
Constant	-2.05** (0.93)	-3.86	-0.23	
Number of Obs. = 525				
Log likelihood = -273.3				
Pseudo R^2 = 0.137				
LR chi2 = 86.98 Prob > chi2 = 0.000				

Robust Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

In this regression, Egyptian households are more likely to support air pollution control projects when they are well informed about the negative consequences of pollution on their health, and when they have a higher income, a higher educational level, and are of younger age. Also, the residents of Greater Cairo, and outdoors workers are more likely to support pollution control projects compared to the residents of Alexandria, and indoors workers. On the other hand, the probability of expressing a positive WTP for controlling air pollution decreases with age (more than 60 years old), and among respondents who already have a severe health conditions such as lung cancer. Factors such as gender, and low income have been found to be statistically insignificant within this sub-group, in contrary to the results obtained from the pooled sample.

Table (5A.4): Factors affecting the WTP in the first sub-sample using the Interval-Data Method

WTP	**Coef.**	**[95% Conf. Interval]**	
Gender	-42.1*		
	(24.9)	-90.9	6.9
Residency	42.4**		
	(20.9)	1.38	83.5
Residential with small industries	52.9**		
	(24.6)	4.65	101.14
Both residential and industrial	29.7		
	(27.6)	-24.41	83.89
Age Group (1)	54.61**		
	(21.78)	11.92	97.29
Age Group (3)	-26.86		
	(65.1)	-154.43	100.7
Years of Schooling	22.98**		
	(10.39)	2.62	43.3
Low Income	-50.62*		
	(29.83)	-109.1	7.85
High Income	19.98		
	(24.1)	-27.16	67.12
Having children	48.52**		
	(21.73)	5.9	91.1
Good Health	-21.66		
	(27.92)	-76.38	33.1
Poor Health	6.52		
	(7.43)	-8.035	21.07
Low Medical expenses	-47.81**		
	(21.1)	-89.2	-6.52
High Medical expenses	-56.1		
	(41.98)	-138.3	26.26
Information	25.99		
	(21.9)	-16.95	68.94
Air Quality (work)	-64.78***		
	(21.17)	-106.27	-23.28
Protective Behaviour	154.98***		
	(42.16)	72.35	237.6
Constant	-116.55		
	(169.02)	-447.8	214.72
Number of Obs. = 372			
Log likelihood = -425			
AIC = 888			
Wald chi2 = 64.63 Prob > chi2 = 0.000			

Robust Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

It worth mentioning that marginal effects are not separately reported for this model, thus the coefficients reported for this model indicate the marginal effect of each variable on the estimated WTP value. In this model, the socio-demographic characteristics of the households which may positively affect the amount they are willing to pay in order to reduce $PM_{2.5}$ air pollution include living in Greater Cairo, particularly living in the more polluted areas, having a higher educational level, having children, and also whether the respondent is applying some protective measures (having an air purifier installed in his/her house). In addition, the respondents who are females and those at a younger age (24-39 years old) are more likely to pay additional amounts for improving air quality. On the other hand, the negative coefficients indicate that respondents who have low income, and those who do not consider air pollution to be a problem (have rated air pollution in their area of work as good or very good), are less likely to pay an additional amount for reducing $PM_{2.5}$ air pollution.

Table (5A.5): Estimates of WTP for the first sub-sample using both the Probit and Bivariate Probit Models

	Single-bounded Probit Model		Double-bounded Bivariate Probit Model	
	Full Model	**Bid only**	**Full Model**	**Bid only**
Bid 1	-0.005*** (0.001)	-0.004*** (0.000)	-0.004*** (0.001)	-0.003*** (0.000)
Gender	-0.303* (0.183)		-0.304* (0.183)	
Residency	0.332** (0.166)		0.332** (0.165)	
Age Group 1	0.293* (0.176)		0.281* (0.166)	
Age Group 3	0.444 (0.597)		0.353 (0.673)	
University	0.433* (0.254)		0.475* (0.259)	
Secondary	-0.365 (0.420)		-0.353 (0.424)	
Low Income	-0.626* (0.344)		-0.598* (0.338)	
High Income	0.112 (0.181)		0.108 (0.177)	
Having Children	0.353** (0.175)		0.313* (0.162)	
Health Statues	-0.126 (0.163)		-0.460* (0.246)	
Air Quality	-0.375** (0.163)		-0.393** (0.156)	
Constant	1.429*** (0.337)	1.487*** (0.208)	1.398*** (0.316)	1.45*** (0.206)
Rho			0.34 (0.154)	0.33 (0.14)
Number of Obs.	372	372	372	372
Log Likelihood	-180.43	-197.05	-418.55	-443.5
LR chi2	50.79	17.55	60.47	16.5
Prop > chi2	0.000	0.000	0.0001	0.0003
Wald test for Rho = 0 (Chi2)			4.1	5.2
Prop > Chi2			0.043	0.023
Pseudo R^2	0.123	0.042	0.056	
AIC	386.86	398.10	891.1	897.1
Mean/Median WTP	**377.97 LE**	**399.1 LE**	**379.4 LE**	**405.9 LE**
LB	322.96 LE	332.02 LE	320.3 LE	335.2 LE
UB	500.89 LE	575.86 LE	509 LE	599 LE
CI/Mean	0.47	0.61	0.50	0.65

Robust Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

Table (5A.6): Testing the consistency of the responses with economic theory in the second sub-sample: a Bivariate Probit model with only bid prices as covariates.

	Pooled	5 in 10000	10 in 10000
Answer 1			
Bid 1	-0.004***	-.0037***	-0.0045***
	(0.000)	(0.001)	(0.001)
Constant	1.61***	1.44***	1.79***
	(0.206)	(0.288)	(0.299)
Answer 2			
Bid 2	-0.002**	-0.0022	-0.0015
	(0.001)	(0.0014)	(0.0014)
Constant	0.687**	0.655*	0.704*
	(0.266)	(0.374)	(0.379)
Rho	0.41	0.57	0.20
	(0.137)	(0.177)	(0.207)
Number of Obs.	404	201	203
Log Likelihood	- 475.2	-242.6	-229.16
Wald chi2	22.3	9.21	13.04
Prop > chi2	0.000	0.010	0.0015
chi2 (LR test of Rho = 0)	8.2	8.02	0.92
Prop > chi2	0.004	0.005	0.336

Robust Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

Table (5A.7): Factors affecting the WTS pollution control projects in the second sub-sample

WTS	**Coef.**	**[95% Conf. Interval]**		**Marginal Effects**
Health Risk Level	0.259* (0.136)	-0.008	0.525	0.066** (0.035)
Residency	0.541*** (0.139)	0.268	0.814	0.139*** (0.035)
Gender	0.135 (0.161)	-0.181	0.45	0.035 (0.04)
Age Group (1)	0.211 (0.150)	-0.082	0.504	0.054 (0.036)
Age Group (3)	-1.367*** (0.244)	-1.84	-0.89	-0.35*** (0.065)
University	0.161 (0.144)	-0.122	0.44	0.041 (0.037)
Secondary	-1.159** (0.493)	-2.12	-0.193	-0.297** (0.128)
Low Income	-0.329 (0.249)	-0.82	0.16	-0.084 (0.065)
High Income	0.257* (0.156)	-0.048	0.56	0.066* (0.039)
Health Status	0.566*** (0.178)	0.216	0.914	0.145*** (0.044)
Number of Diseases	-0.115*** (0.042)	-0.197	-0.032	-0.03*** (0.009)
Air Quality (residency)	-0.337** (0.143)	-0.62	-0.057	-0.086** (0.036)
Full Health Insurance	-0.566*** (0.215)	-0.66	0.065	-0.145** (0.053)
No Health Insurance	-0.297 (0.185)	-0.98	-0.145	-0.076 (0.047)
Job type	0.493*** (0.179)	0.14	0.84	0.126** (0.046)
Constant	-0.046 (0.321)	-0.67	0.58	
Number of Obs. = 526				
Log likelihood = -240.8				
AIC = 513.640				
Pseudo R^2 = 0.155				
LR chi2 = 88.13 Prob > chi2 = 0.000				

Robust Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

The results demonstrate that many factors have a significant positive influence on Egyptian households' willingness to support air pollution control projects in order to reduce the mortality risk associated with poor air quality, including the amount of risk level reduction, having a higher income, suffering from air pollution-related diseases, and working in an outdoors job. Also, residents of Greater Cairo are more likely to support pollution control projects compared with Alexandria's residents. On the other hand, the probability of expressing a positive WTP for controlling air pollution such as to reduce the mortality risk associated with it decreases with age (more than 60 years old), already having a very poor health status, having a low educational level, having full health insurance coverage, and whether the respondent doesn't consider air pollution to be a problem (has rated air pollution in his/her area of residence as good or very good).

Table (5A.8): Factors affecting the WTP in the second sub-sample using the Interval-Data Method

WTP	**Pooled**	**5 in 10000**	**10 in 10000**
Health Risk Level	41.2** (19.9)	-----	-----
Gender	-12.2 (22)	6.13 (31)	-73.8** (32.6)
Residency	68.9*** (20.6)	91.7** (36)	48.13** (24.5)
Residential	34.9 (21.8)	70.10** (30.6)	-11.29 (30.2)
Both residential and industrial	58.3** (25.3)	84.7* (46.27)	14.41 (28.42)
Age Group (1)	33.8 (18.9)	19.3 (29.46)	57.8** (24.7)
Age Group (3)	-23.7* (50.5)	-57.31 (56.25)	-41.7 (36.3)
University	31.3 (20.5)	82.74** (36.6)	21.46 (32.18)
Secondary	-57.4 (104.8)	-35.37 (66.1)	-7.17 (40.2)
Low Income	-1.32 (25.4)	-47 (39.5)	-118.4*** (41.94)
High Income	39.7** (22.1)	21.7 (33.3)	88.85*** (30.65)
Health Status	-36.1** (18.4)	-67.48** (34.2)	-24.7 (47.8)
Protective Behaviour	142.8*** (41.3)	215.5*** (58.53)	29.42 (55.8)
Number of Diseases	-----	-16.84* (9.87)	-44.7** (20)
Full Health Insurance	-----	11.3 (42.43)	13.5 (37.3)
No Health Insurance	-----	-61.19* (33.2)	-67.8** (29.6)
Air Quality (work)	-51.3** (19.2)	-----	-----
Constant	218.7*** (40.2)	130* (67)	348.6*** (56.4)
Number of Obs.	404	201	203
Log likelihood	-462.6	-227.44	-208.54
AIC	957.28	488.88	451.08
Wald chi2	53.8	41.76	53.77
Prob > chi2	0.000	0.0002	0.000

Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

The socio-demographic characteristics of the households such as living in Greater Cairo, particularly living in the more polluted areas, having a higher income, and whether the respondent is applying some protective measures, in addition to the level of mortality risk reduction are considered as important factors that may positively affect the amount which people are willing to pay in order to reduce their mortality risk. In this regression, the negative coefficients indicate that respondents who already have a poor health status, those who are above 60 years of age, and those who do not consider air pollution as a problem, are less likely to pay an additional amount for reducing the mortality risk attributable to $PM_{2.5}$ air pollution.

Table (5A.9): WTP for improved air quality in Greater Cairo and Alexandria using the Interval-Data Model

	Coef.	**[95% Conf. Interval]**
Residency	65.6***	(22.5 – 108.8)
	(22)	
Constant	263.6***	(227.8 – 229.4)
	(18.3)	
Number of Obs. = 372		
Log Likelihood = -456.7		
Wald chi2 = 8.88		
Prop > chi2 = 0.003		

Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

Table (5A.10): WTP for improved air quality in Greater Cairo and Alexandria using the Interval-Data Model

	Coef.	**[95% Conf. Interval]**
Residency	67.4***	(27.7 – 107)
	(20)	
Constant	254.7***	(221.4 – 288)
	(17)	
Number of Obs. = 404		
Log Likelihood = -487.6		
Wald chi2 = 11.09		
Prop > chi2 = 0.000		

Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

Appendix (5B): The Questionnaire

1. Payment Vehicle

Various payment vehicles have been applied in CVM studies for evaluating environmental goods, some of these vehicles have been rather general, such as a general increase in prices and taxes (Boyle et al., 1994 and Bergstrom et al., 2004), while others have been more specific such as income tax (Loomis and duVair, 1993 and Morrison et al., 2000), and utility bills (Brookshire et al., 1980; Powell et al., 1994).

The payment method should meet some criteria in order to prevent rejective responses and reduce bias in respondents' valuations, such as that it should be realistic, credible, acceptable, and coercive (Mitchell and Carson, 1989). The proper level of realism for the payment mechanism has been subject to much debate within the CVM studies, as there is evidence that the payment mechanism can influence the WTP estimates (Johnston et al., 1999; Campos et al., 2007), and that there is a trade-off between realism and the probability of rejecting the payment vehicle (Mitchell and Carson, 1989). We have paid special attention to evaluating the various payment vehicles in order to identify the one which may have a relatively small impact on the WTP estimates, and in order to choose the method that is most realistic and related to the respondents' actual experience.

As mentioned earlier, the selected payment vehicle used in this study is higher prices for marketed goods due to an increase in the general sales tax paid by respondents over a ten-year period. This method seems to be realistic in the sense that any improvements in air quality would be partly funded by the government and therefore would expectedly result in higher tax levels. Taxes are usually regarded as a universal payment mechanism and are commonly recommended in CVM studies due to concerns over payment vehicle bias. However, using taxes as a payment vehicle has some disadvantages, especially with regard to incentives, as paying higher taxes is not emotionally neutral for most people, and regulatory agencies often lack public trust and credibility, and therefore using taxes as a payment vehicle may increase the number of protest responses (Chilton and Hutchinson, 1999). However, the realistic possibility of this particular payment mechanism warrants its selection, and also the use of a voter referendum elicitation format (where people vote yes or no) makes taxes the most logical and credible payment vehicle.

The sales tax rate in Egypt is a tax charged to consumers based on the purchase price of all goods and services. Revenues from the sales tax has been an important source of income for the government of Egypt since it was first applied in 1991. One standard rate of 14% applies to all goods and services, except for machinery and equipment which are subject to a 5% rate. Some goods and services are also subject to a Schedule Tax, which is applied at different rates depending on the nature of the good or service. Although a Value Added Tax (VAT) system was officially introduced in 2016 as a replacement for the General Sales Tax Law, the public in Egypt still refer to this tax as a sales tax.

Furthermore, we found that the other possible modes of payment, such as raising utility bills, or increasing property or income taxes may be inappropriate due to many reasons. For example, in the case of increasing the property tax, the Egyptian taxation system does not have the equivalent of the UK council tax. In Egypt, property tax is imposed on buildings, and is borne solely by the owner, whether a natural person or a corporate body. The percentage of Egyptian families who own their homes in Greater Cairo is only about 60 percent, and therefore an increase in property tax would not be a realistic payment vehicle for many Egyptian households. Similarly, an increase in income tax would also not be appropriate, because in the past several decades the informal economy in Egypt has grown from being negligible to involving almost half of the population. As a result, there are difficulties in collecting income tax in Egypt, as the informal economy constitutes up to 50 percent of the country's GDP and provides 68 percent of the jobs. Raising the utility bills as a payment method would not also be a realistic option, with an estimated 40 million informal settlement dwellers in Egypt out of a national population of some 100 million, which translates into about 40% of the total population living in informal areas, with 60% of these areas being in Greater Cairo, where it is estimated that about 1 million families have informal electricity and water connections, thus making it difficult to use utility bills as a payment vehicle in Egypt. Therefore, the use of general sales tax on goods purchased as the payment vehicle may be the most appropriate, if not the only realistic, option for our scenarios.

2. Survey Questionnaire and Responses

You are invited to participate in this survey, which aims to provide the necessary information for a research study about air pollution health risk assessment, and about the economic value of air quality in Egypt.

We really appreciate your help in completing this survey, which will take approximately 15 minutes. Please read the following information carefully, before deciding whether you wish to participate or not.

What are the study objectives? The study aims to measure households' willingness to pay (WTP) for improving air quality in Greater Cairo and in Alexandria, and for reducing the health risk associated with air pollution.

What will I have to do? This study entails completing the survey. In the First two parts you will be asked some questions related to demographic characteristics and environmental knowledge. In the Third part you will be asked to carefully read the information provided about air pollution, and then to answer the subsequent questions. In the last part you will be asked some questions related to demographic characteristics and the economic burden of diseases.

Who can participate? A single representative of any household in both Greater Cairo and Alexandria, of age 24 and up.

Is my participation confidential? Participants in this study are guaranteed confidentiality of any information they provide. The data you provide is fully anonymous, and we will not collect or ask you to provide any personal or identifying information. We have no way of linking the responses back to an individual, and it is not possible for us to associate data with the IP address from which the survey was completed. The anonymized data may be archived and shared with others for legitimate research purposes.

Do I have to participate? Participation in this study is voluntary and you can decide to stop participating in the survey at any point by closing the internet browser. You can also choose to omit any questions that you do not wish to answer. Partially completed responses will not be analyzed.

If you have any questions or queries, please feel free to email the researcher at: s.ghanem@uea.ac.uk

Thank you for reading this information and for considering participating in this study.

By proceeding to the survey, you confirm that:

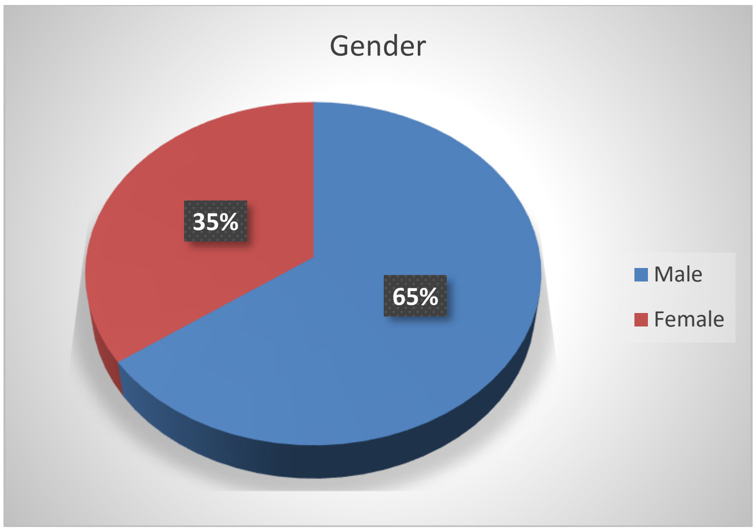
- You have read and understood the information sheet for this project.
- You understand the purposes of the study and what it involves.
- You understand that your participation is voluntary and that you are free to withdraw at any time without giving a reason.
- You understand that your anonymized data may be archived and shared with others for legitimate research purposes.

The number of households participating in the study

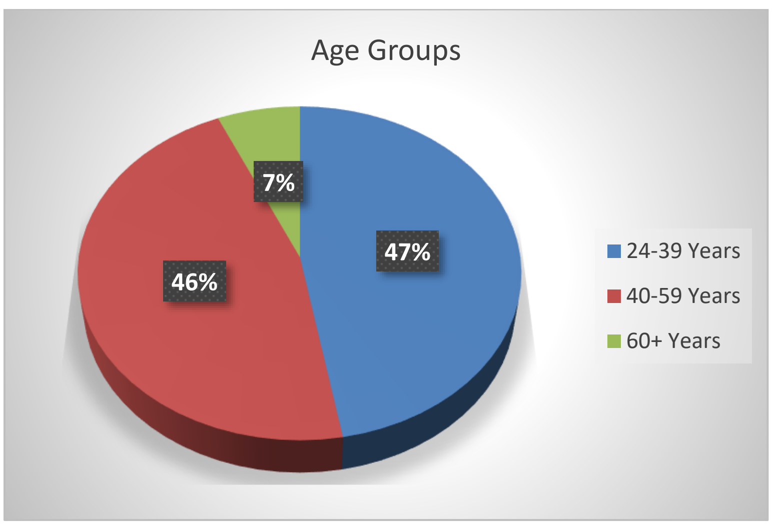
Accept and Participate	94.64%	1060
Do not Accept	5.36%	60
Total	100%	1120

Part (1): Demographic Characteristics (1):

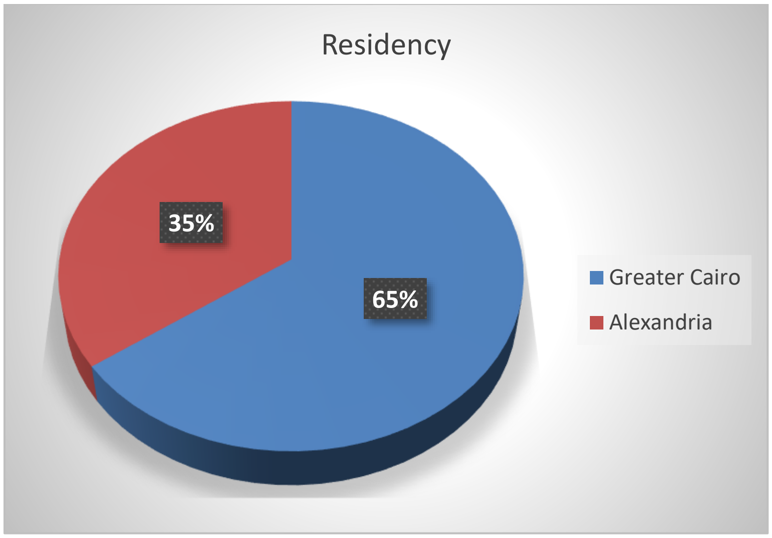
1. Please specify your gender:



2. Please indicate your age:



3. What is your area of residence?



The Number of Districts (used in the study) and Responses by District Type in Greater Cairo

District Type	Number	Responses
A residential area	21	343
A residential area with some small industries	17	202
Both a residential and an industrial area	9	145
Total	47	690

The Number of Districts (used in the study) and Responses by District Type in Alexandria

District Type	Number	Responses
A residential area	19	166
A residential area with some small industries	14	96
Both a residential and an industrial area	7	108
Total	40	370

The distribution of responses by district in Greater Cairo

District	%	Responses	District	%	Responses
Shubra El Kheima	3.33%	23	Mohandessin	1.88%	13
Shubra	3.91%	27	Sheikh Zayed	1.30%	9
El Marg	2.90%	20	6 of October	2.75%	19
El Matareya	1.88%	13	Kirdasah	0.43%	3
Ain Shams	4.78%	33	Badr	1.30%	9
Heliopolis (Roxy, Korba, Medan El Gammah)	16.81%	116	Obour	2.17%	15
Nasr City	7.39%	51	New Cairo	2.32%	16
Abbassia	3.04%	21	Madinaty	1.01%	7
Mokattam	2.17%	15	Fifth Settlement	2.32%	16
Old Cairo	1.16%	8	New Heliopolis	0.14%	1
Maadi	3.91%	27	El Shorouk	1.45%	10
Garden City	1.45%	10	El Rehab	1.01%	7
El-Sida Zainab	1.30%	9	Hadayek El-Kobba	2.32%	16
Rod El Farag	0.43%	3	El-Khalifa	0.14%	1
El Zawia El-Hamra	0.87%	6	El-Sharabia	0.58%	4
El-Nozha	2.17%	15	Elsahel	0.29%	2
Zamalek	1.59%	11	El-Zeitoun	1.30%	9
Tahrir Square	1.01%	7	Boulaq	1.01%	7
Downtown Cairo	2.17%	15	El-Gamaleya	0.29%	2
Helwan	4.35%	30	Manshiyat Naser	1.16%	8
15th of May	2.17%	15	El-Basateen	1.88%	13
Dokki	1.88%	13	Dar El-Salam	2.17%	15

The distribution of responses by district in Alexandria

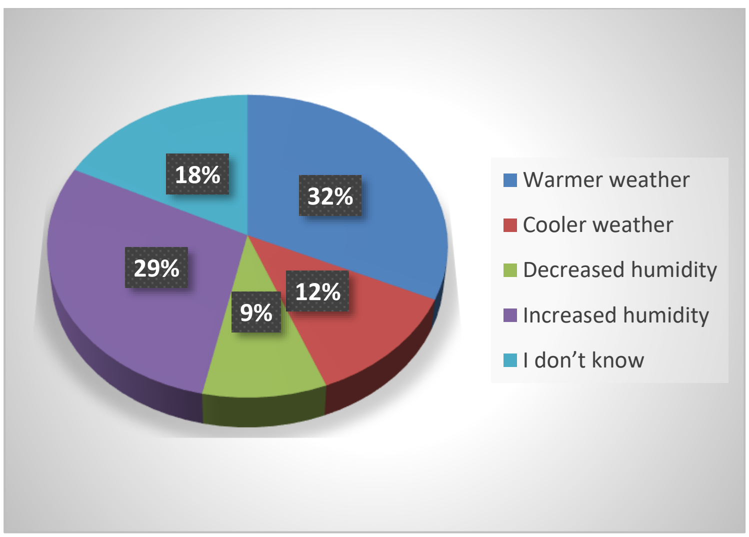
District	%	Responses	District	%	Responses
El-Shatby	3.24%	12	Al-Manshiya	2.16%	8
Asafra	3.51%	13	Baccos	0.81%	3
Allban	0.81%	3	Bahary	2.16%	8
Al-Mamurah	4.32%	16	Smouha	3.78%	14
El-Mandara	2.43%	9	Shods	0.54%	2
Bolkly	1.89%	7	Victoria	1.08%	4
Gleem	5.95%	22	Camp Chezar	0.81%	3
Gianaclis	1.35%	5	Mahatet El-Raml	2.97%	11
Zizinia	2.43%	9	Mahatet Masr	1.62%	6
Saba Basha	2.16%	8	Ras El-Tin	0.81%	3
San Stefano	2.97%	11	Al-Kabary	4.05%	15
Stanley	0.81%	3	Al- Max	3.78%	14
Sidi Bishr	1.89%	7	Al Wardiyan	2.70%	10
Sidi Gaber	3.24%	12	Amreya	4.59%	17
Fleming	0.81%	3	El-Dekheila	5.41%	20
Kafr Abdu	1.35%	5	Al-Seyouf	5.68%	21
Louran	2.43%	9	El-Awaied	2.97%	11
Sidi Gaber El Mahata	1.89%	7	Azarita	2.16%	8
Al-Montazah	1.35%	5	Al-Ibrahimiyya	5.14%	19
Al-Attarin	0.81%	3	Al-Hadrah	1.08%	4

Part (2): Environmental Knowledge[134]:

1. Carbon dioxide has increased significantly as a result of fossil fuels burning.

What do you think is the direct effect of increasing carbon dioxide concentration in the atmosphere on Earth?

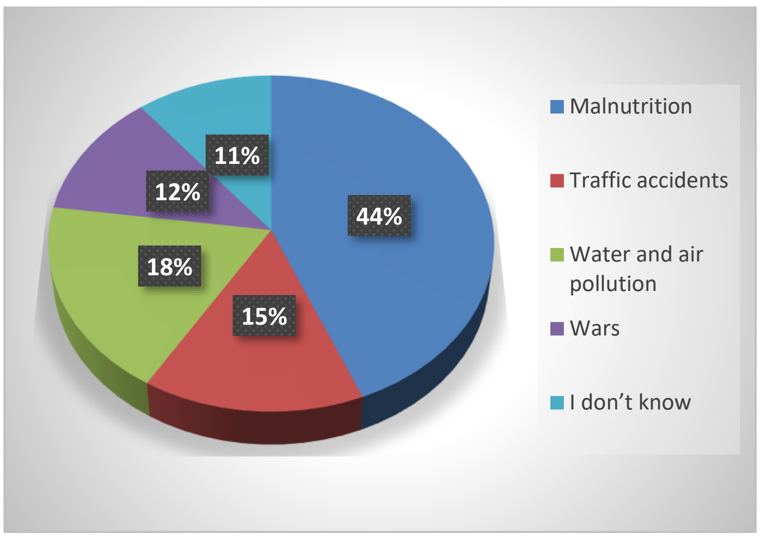
Warmer weather	329
Cooler weather	126
Decreased humidity	97
Increased humidity	300
I don't know	182
Other (10 of them have mentioned global warming)	26
Total	1060



[134] In this Section, for the questions related to environmental Knowledge, the highlighted cell in the table refers to the correct answer.

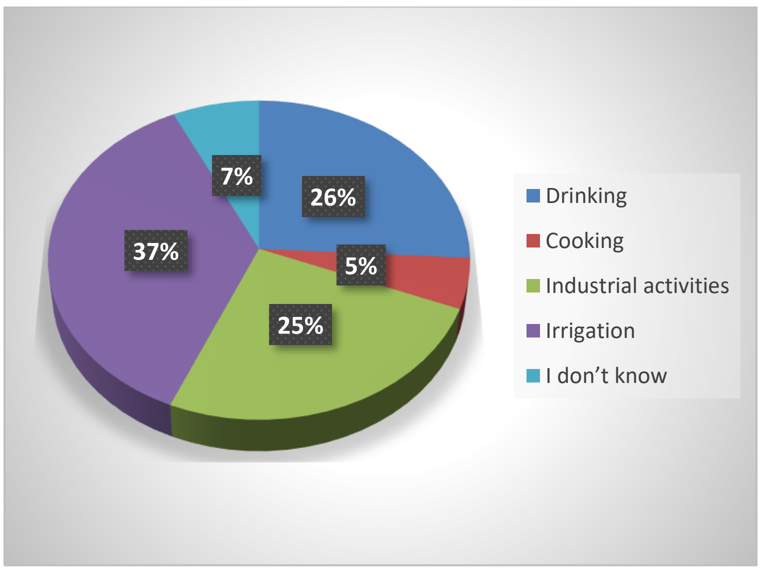
2. The main cause of childhood deaths worldwide is:

Malnutrition	457
Traffic accidents	156
Water and air pollution	193
Wars	126
I don't know	112
Other	16
Total	1060



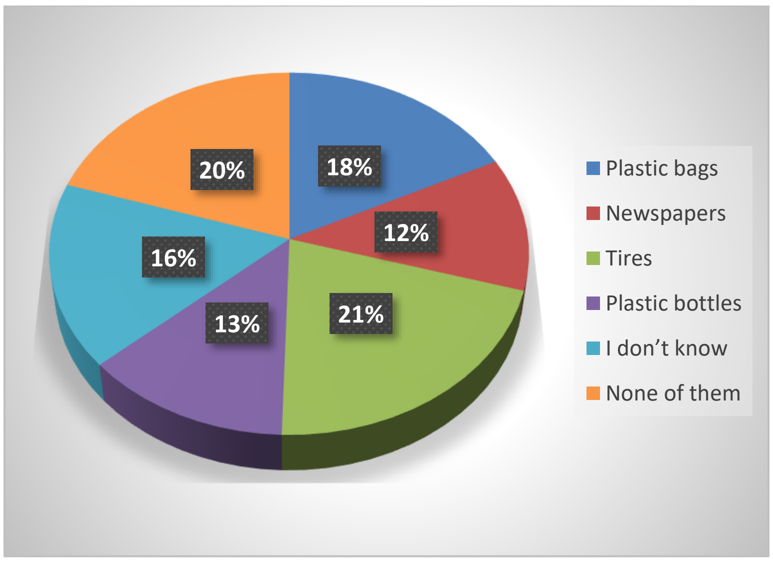
3. Nearly 70% of fresh water withdrawn for human use is used for:

Drinking	273
Cooking	54
Industrial activities	268
Irrigation	384
I don’t know	75
Other	6
Total	1060



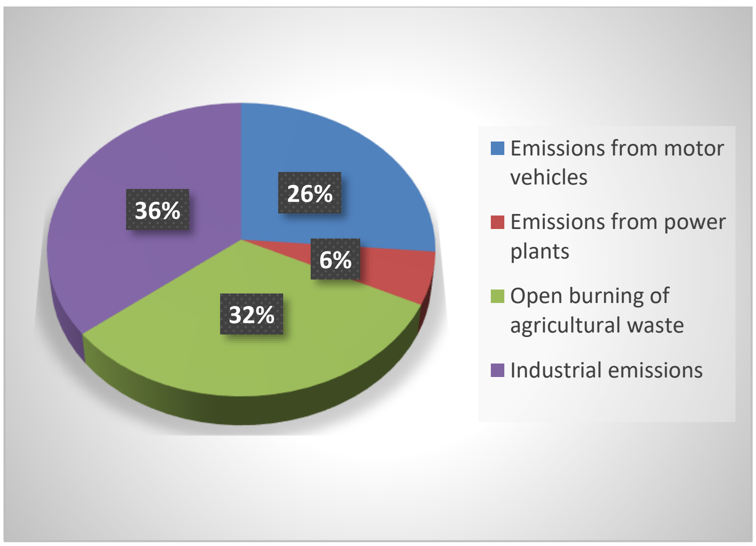
4. Which of the following items cannot be recycled and used again?

Plastic bags	187
Newspapers	126
Tires	222
Plastic bottles	138
I don't know	175
None of them	212
Total	1060

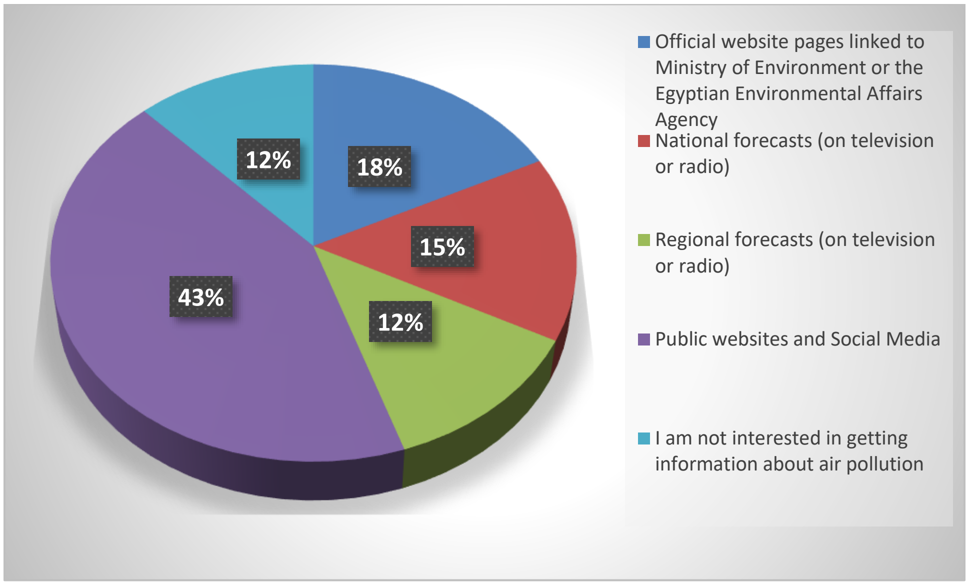


5. Could you point out for the main reason for the occurrence of the black cloud phenomenon in Cairo?

Emissions from motor vehicles	271
Emissions from power plants	60
Open burning of agricultural waste	332
Industrial emissions	367
Other	30
Total	1060



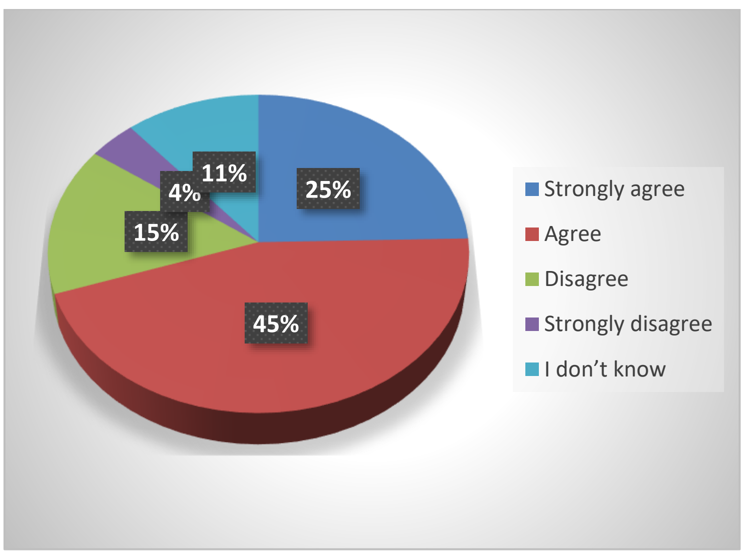
6. What are the main methods you are using to obtain information about air quality, emissions and the impact of exposure? (please select all applicable)



<u>Part (3): Risk perception</u>

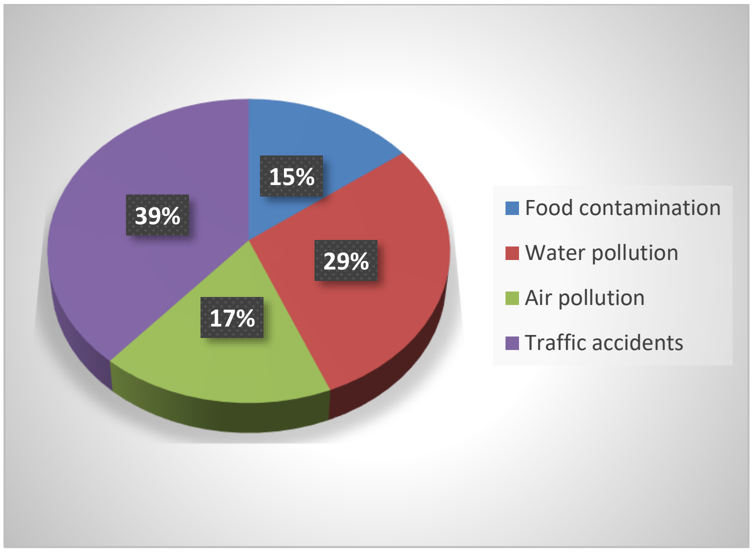
1. To what extent do you agree or disagree with the following statement?

"In Egypt, water pollution has a more serious health impact than air pollution"

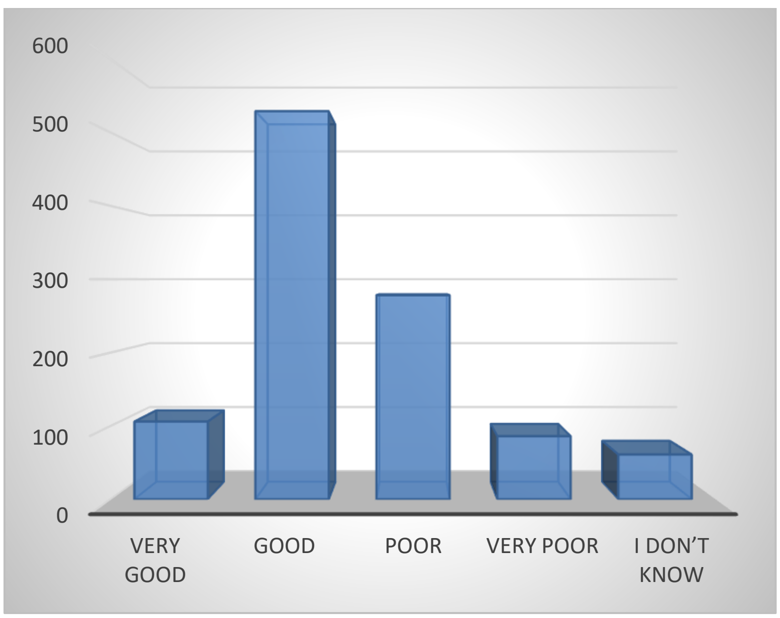


2. Please complete the following statement:

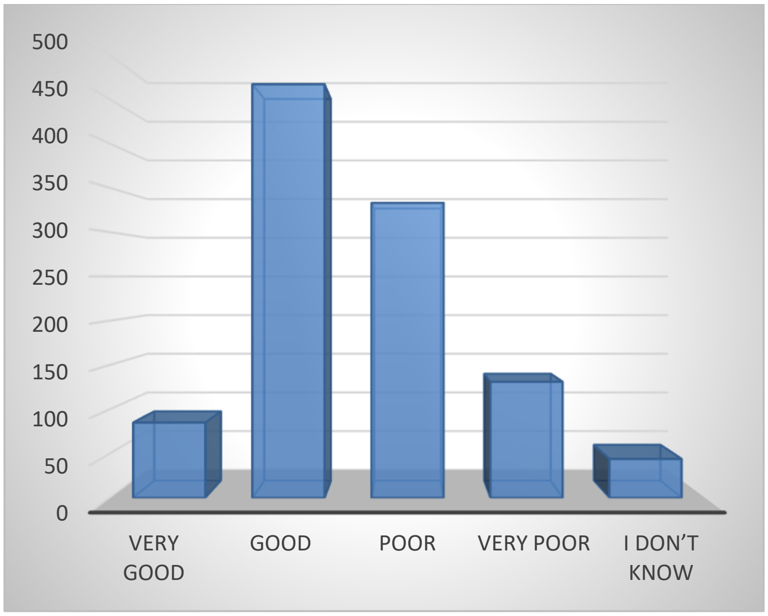
"I am more scared of dying from (...............) than other risks"



3. How do you rate the air quality in your area of residence (e.g. smoke/ haze)?



4. How do you rate the air quality in your area of work (e.g. smoke/ haze)?



Part (3): The WTP Questions

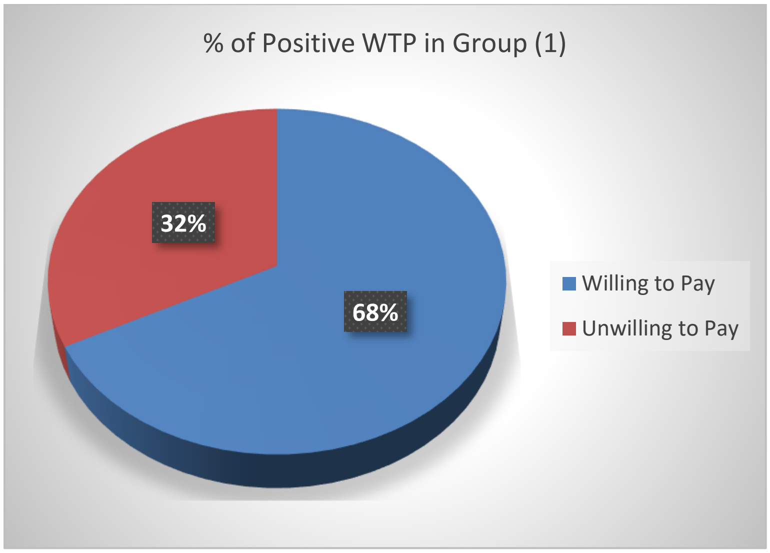
First Scenario: the WTP for a 50% reduction in $PM_{2.5}$ air pollution resulted from industrial activities:

Group (1)/ No Information

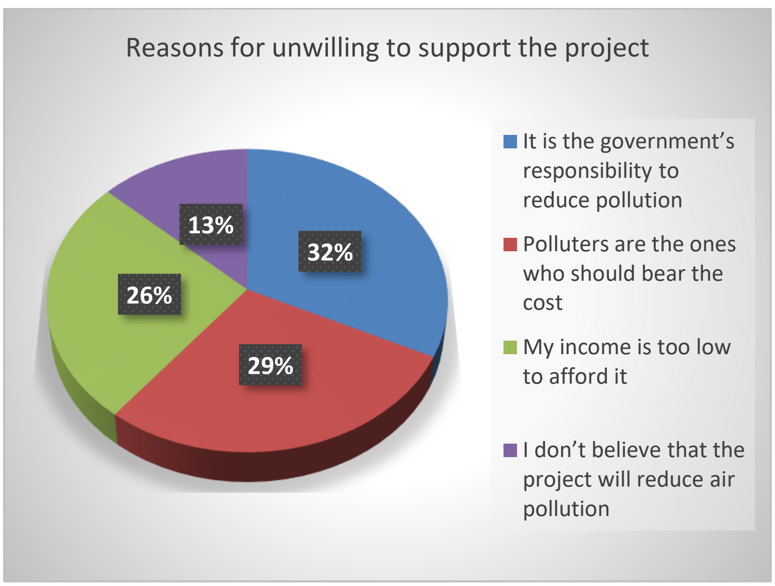
Air pollution is one of the most serious environmental problems in Egypt. Air quality measurements in Egypt indicate dangerous levels of air pollutants, such as lead, carbon monoxide, nitrogen dioxide, sulphur dioxide, Ozone, and suspended PM concentrations, whether PM_{10} or $PM_{2.5}$, with the latter being the more serious problem. The annual average of $PM_{2.5}$ concentration in Egypt is nearly seven times higher than the guideline recommended by the World Health Organization (WHO).

The prevalence of industrial activities in urban areas, especially in heavily populated areas significantly contributes to the increase in $PM_{2.5}$ concentration and poses a persistent risk to public health. The Egyptian government works on reducing industrial smokestack emission levels in urban areas in order to meet the WHO standards, through developing specialized industrial zones. This Relocation of polluting industries to remote areas is expected to significantly reduce particulate matter air pollution in urban settings, possibly cutting $PM_{2.5}$ air pollution by 50%. This project will be funded through increasing sales tax rate on purchased goods.

Q.1. Implementing this procedure will increase the cost of many goods you buy. This would increase your cost of living. If your monthly living expenses increased as a result of implementing this project, would you like the government to implement it?



Q.2. If No: Please explain why you are unwilling to support this pollution control project[135]:



[135] The number of "No" Responses is 88, which represents about 32.47% of the total responses within this sub-group.

Q.2. If Yes: Considering your household's monthly income and expenditures, if the additional cost to your household would be (100, 200, 300) LE per month, would you want these factories to be relocated in order to reduce your exposure to particulate matter air pollution by 50%?

Q.3. If Yes: If the prices of goods increased more than anticipated as a result of implementing this project, and now the additional cost to your household would be (200, 300, 400) LE per month, would you still support this project? Please notice that if you accept, you will lose some of your income that you could have spent on other things costing the same amount.

Q.3. If No: If the prices of goods increased less than anticipated as a result of implementing this project, and now the additional cost to your household would be only (50, 100, 200) LE per month, would you support this project? Please notice that if you accept, you will lose some of your income that you could have spent on other things costing the same amount.

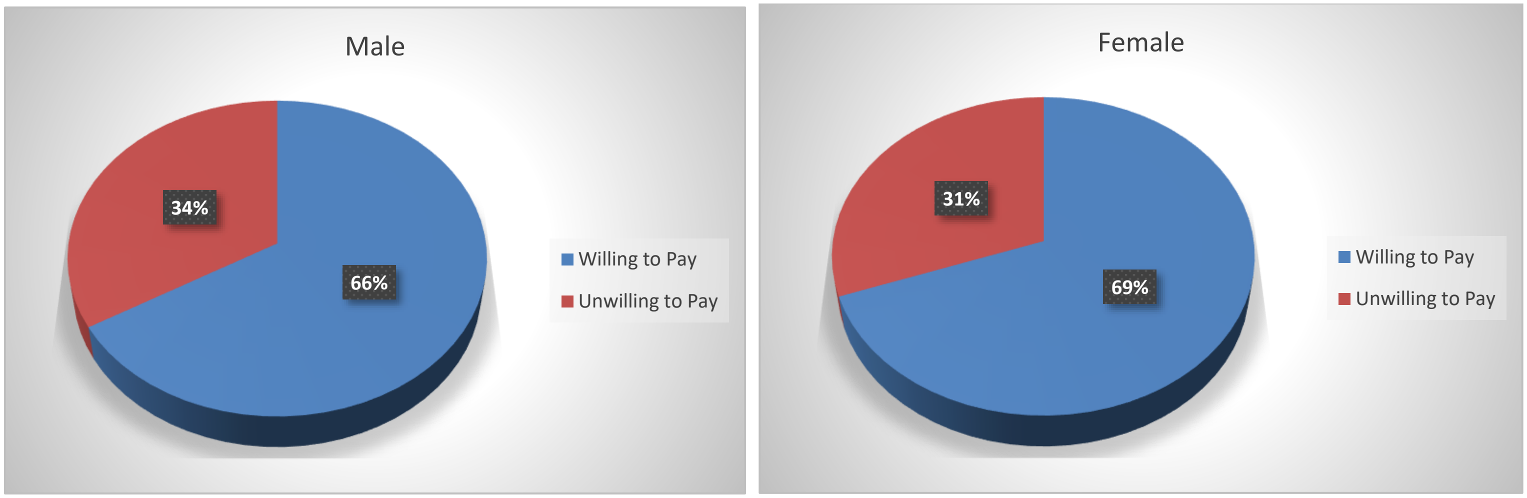
Q.4. Considering your household's monthly income and expenditures, what is the maximum increase in your monthly expenses that you would accept in order to support implementing this project?

Total Sample Size: 271

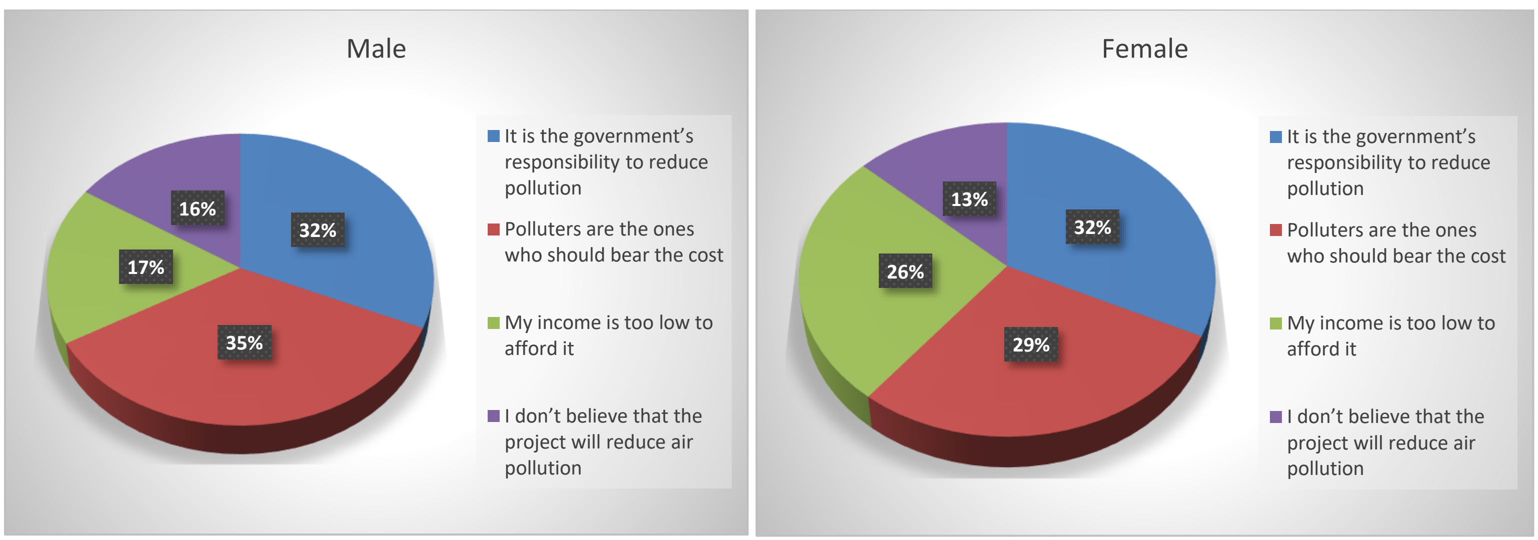
"Yes" Responses: 183 (67.53%)

Starting Bid	100 LE (N = 57)				200 LE (N = 57)				300 LE (N = 69)			
First Response	Yes = 50 (87.72%)		No = 7 (12.28%)		Yes = 41 (71.93%)		No = 16 (28.07%)		Yes = 45 (65.22%)		No = 24 (34.78%)	
Second Bid	200 LE		50 LE		300 LE		100 LE		400 LE		200 LE	
Second Response	Yes = 32 (64%)	No = 18 (36%)	Yes = 5 (71.43%)	No = 2 (28.57%)	Yes = 24 (58.54%)	No = 17 (41.46%)	Yes = 6 (37.5%)	No = 10 (62.5%)	Yes = 30 (66.67%)	No = 15 (33.33%)	Yes = 9 (37.5%)	No = 15 (62.5%)
Follow up for "No-No" Response (open-ended)	(25, 20) Mean = 22.5 LE				(50, 50, 50, 50, 50, 50, 15, 30, 30, 20) Mean = 39.5 LE				(150, 50, 50, 100, 50, 75, 150, 50, 50, 50, 100, 40, 50, 100, 20) Mean = 67.33 LE			

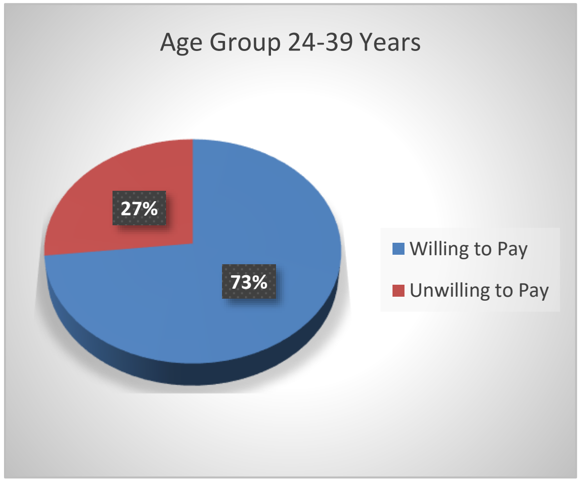
Positive WTP by Gender

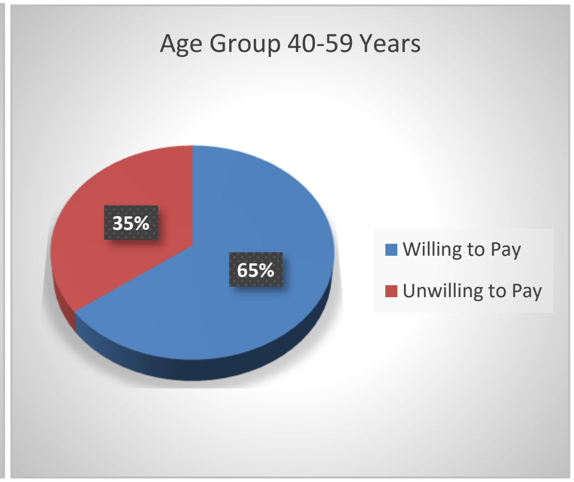


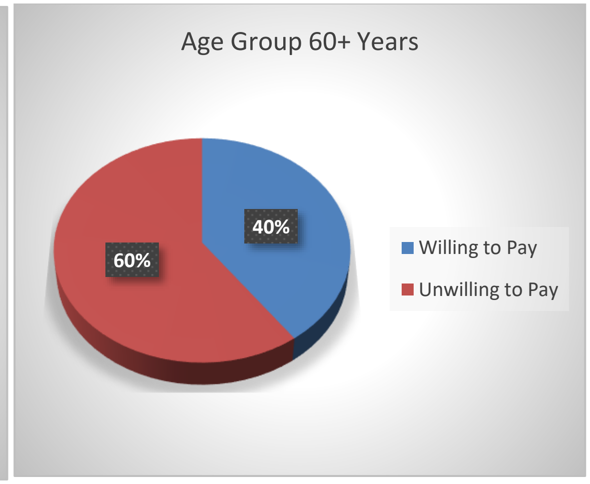
Reasons for unwilling to support the pollution control project



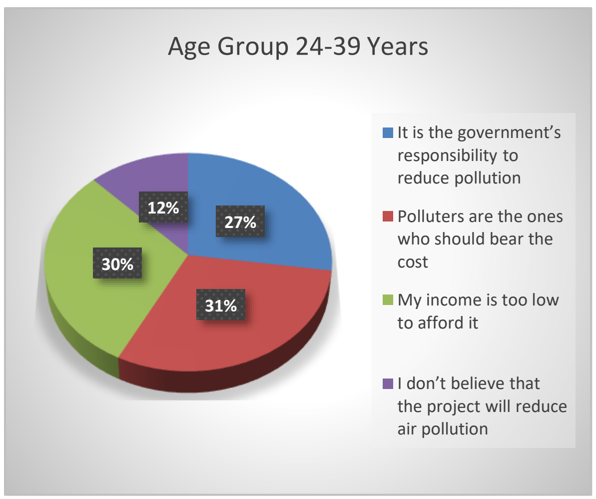
Positive WTP by Age Group

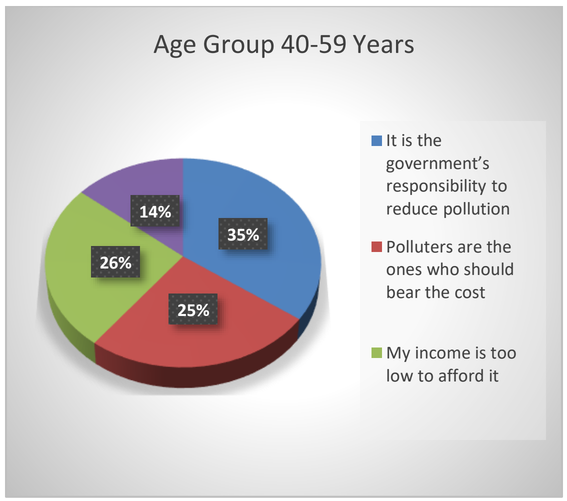


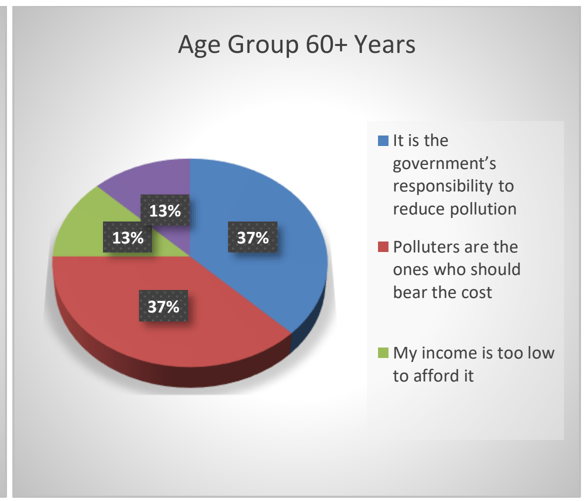




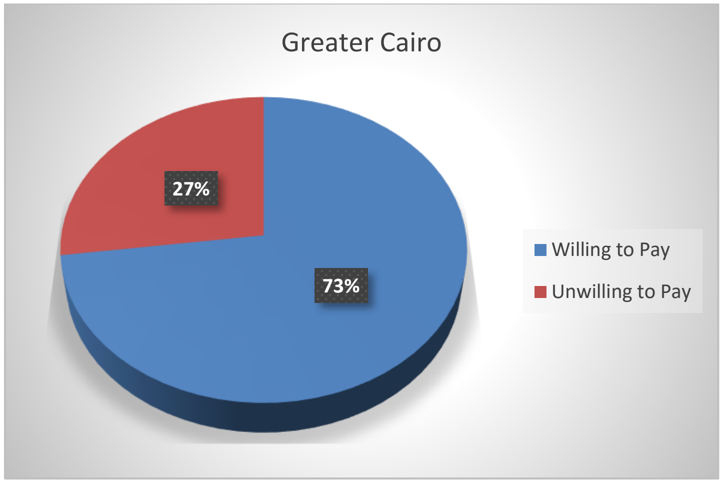
Reasons for unwilling to support the pollution control project

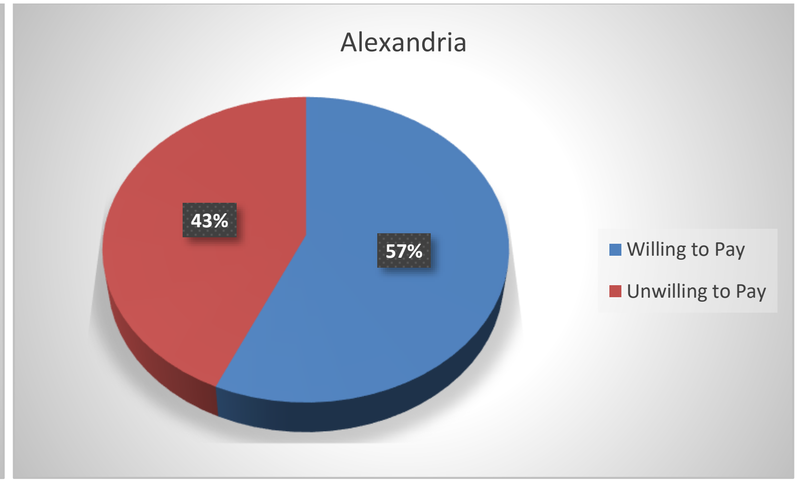




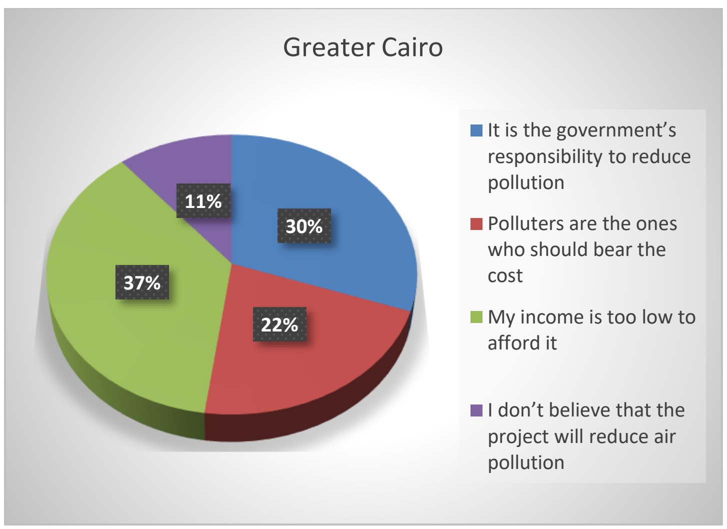


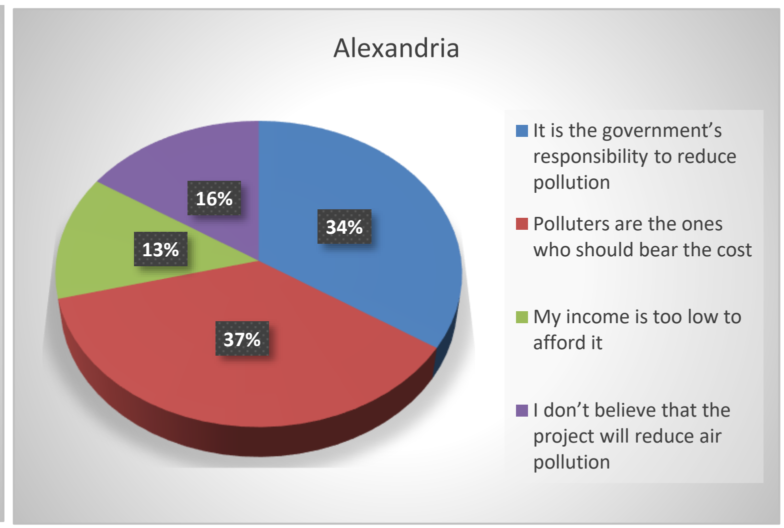
Positive WTP by Residency



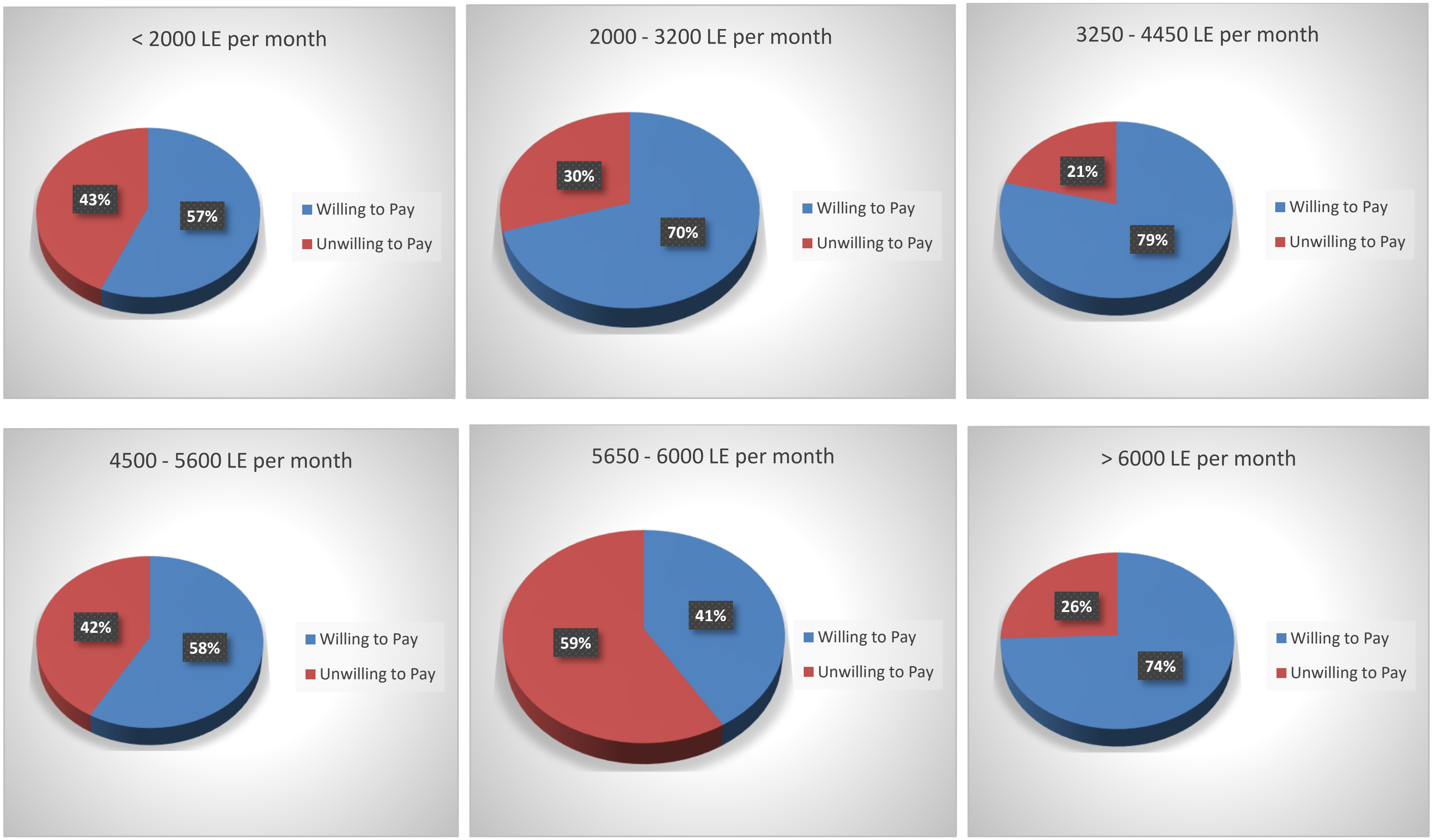


Reasons for unwilling to support the pollution control project

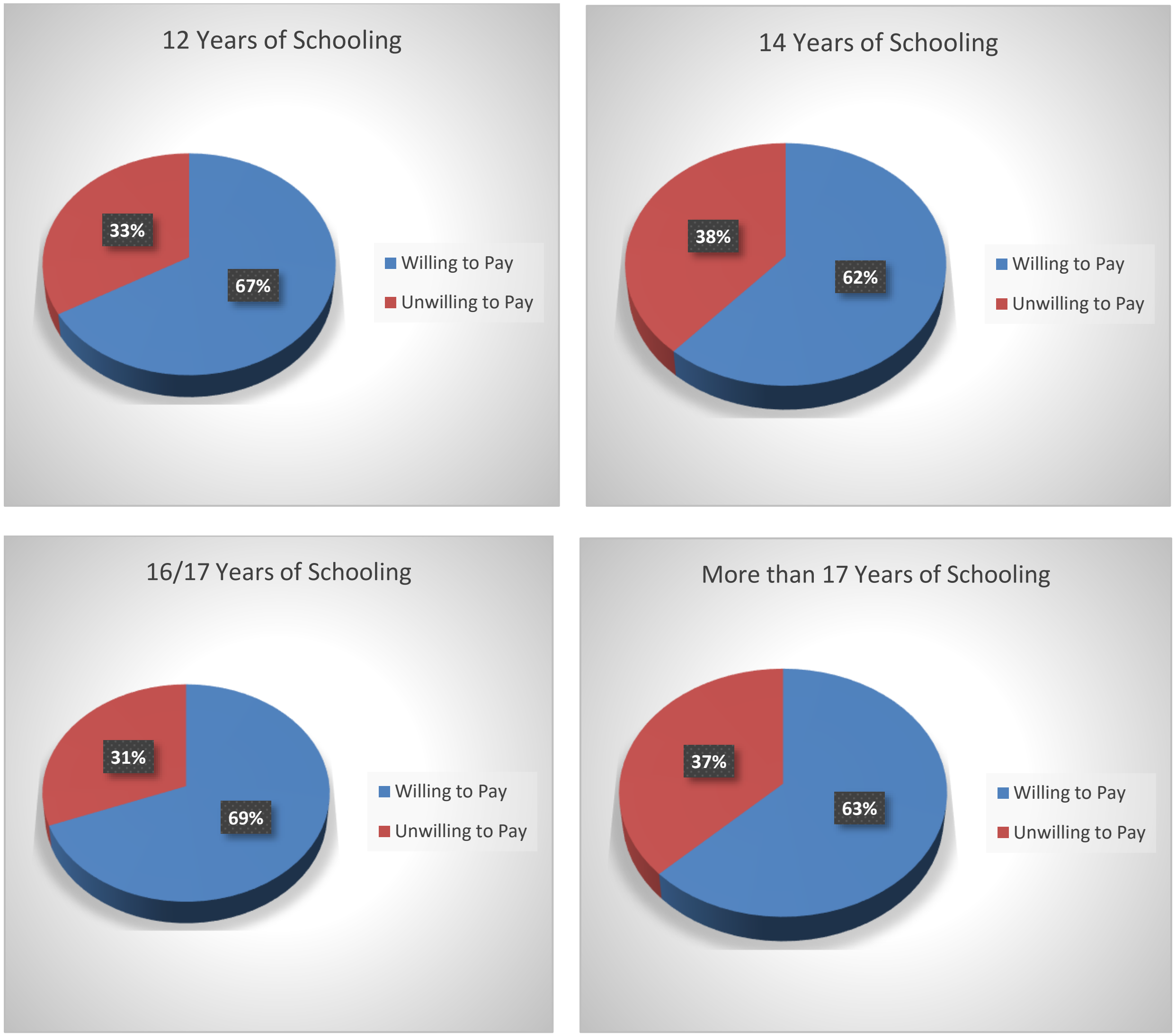




Positive WTP by Income Level



Positive WTP by Educational level



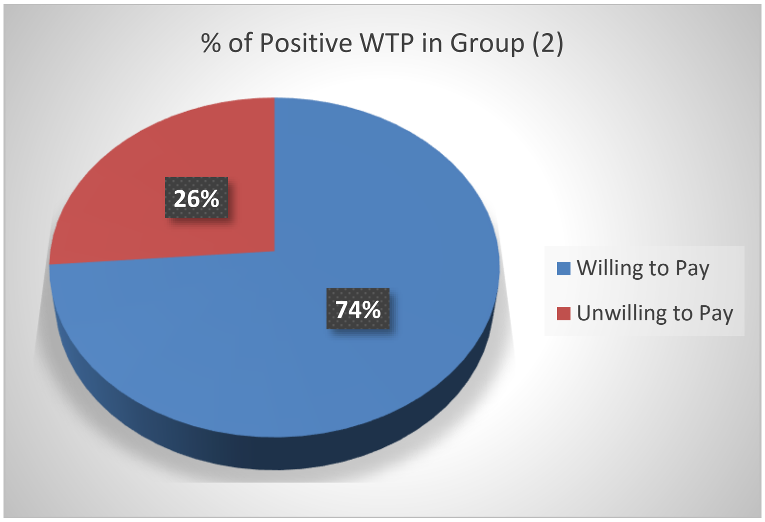
Group (2)/ Information

Air pollution ranks among the top risk factors for premature death and disability worldwide. The World Health Organization (WHO) data reveals that in 2017, ambient air pollution was responsible for about one third of deaths from lung cancer and other respiratory diseases, and from cardiovascular diseases. Suspended particulate matter air pollution (PM) is related to the most serious health impacts, especially fine particles less than 2.5 microns in size ($PM_{2.5}$) Epidemiological evidence indicates that for every 10 $\mu g/m^3$ increase in the concentration of $PM_{2.5}$, there is an increase in the overall mortality by 4%, an increase in mortality due to cardiopulmonary diseases by 6%, an increase in mortality due to lung cancer by 8%, an increase in mortality due to respiratory diseases by 0.58%, and an increase in hospitalization rate by 8%. Also, studies emphasize the link between air pollution and both bladder and liver cancer risks.

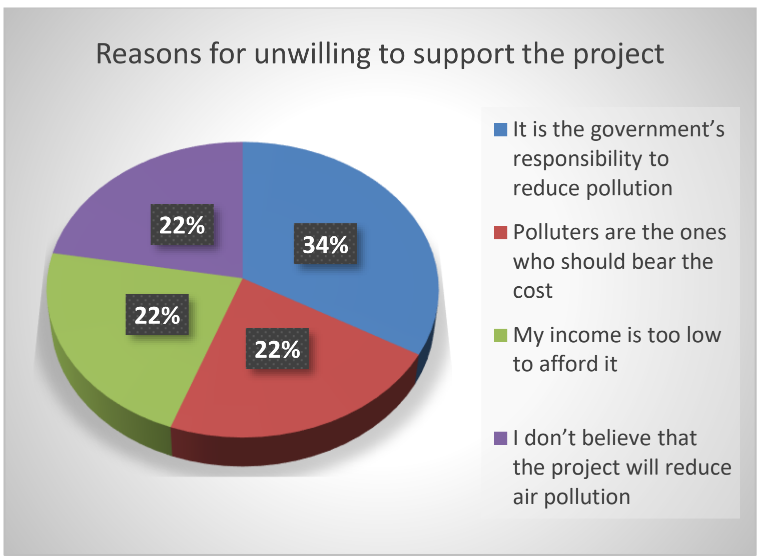
The annual average of $PM_{2.5}$ concentration in Egypt is nearly seven times higher than the guideline recommended by the World Health Organization (WHO). Egypt ranks first worldwide with respect to the prevalence of bladder cancer (causing 7.98 deaths per 100,000 individuals) and ranks fourth with respect to the prevalence of liver cancer (causing 27.42 deaths per 100,000 of individuals). Lung cancer in Egypt, is one of the most common cancers, representing between 5%-7% of all cancers. The country also is among the top ten countries in terms of death from coronary heart diseases (2016.82 deaths per 100,000 individuals).

The prevalence of industrial activities in urban areas, especially in heavily populated areas significantly contributes to the increase in $PM_{2.5}$ concentration and poses a persistent risk to public health. The Egyptian government works on reducing industrial smokestack emission levels in urban areas in order to meet the WHO standards, through developing specialized industrial zones. This Relocation of polluting industries to remote areas is expected to significantly reduce particulate matter air pollution in urban settings, possibly cutting $PM_{2.5}$ air pollution by 50%. This project will be funded through increasing sales tax rate on purchased goods.

Q.1. Implementing this procedure will increase the cost of many goods you buy. This would increase your cost of living. If your monthly living expenses increased as a result of implementing this project, would you like the government to implement it?



Q.2. If No: Please explain why you are unwilling to support this pollution control project[136]:



[136] The number of "No" Responses is 67, which represents about 25.97% of the total responses within this sub-group.

Q.2. If Yes: Considering your household's monthly income and expenditures, if the additional cost to your household would be (100, 200, 300) LE per month, would you want these factories to be relocated in order to reduce your exposure to particulate matter air pollution by 50%?

Q.3. If Yes: If the prices of goods increased more than anticipated as a result of implementing this project, and now the additional cost to your household would be (200, 300, 400) LE per month, would you still support this project? Please notice that if you accept, you will lose some of your income that you could have spent on other things costing the same amount.

Q.3. If No: If the prices of goods increased less than anticipated as a result of implementing this project, and now the additional cost to your household would be only (50, 100, 200) LE per month, would you support this project? Please notice that if you accept, you will lose some of your income that you could have spent on other things costing the same amount.

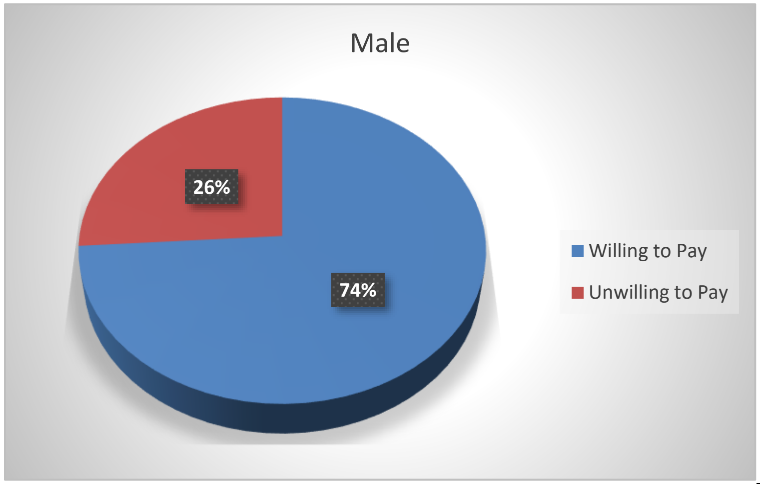
Q.4. Considering your household's monthly income and expenditures, what is the maximum increase in your monthly expenses that you would accept in order to support implementing this project?

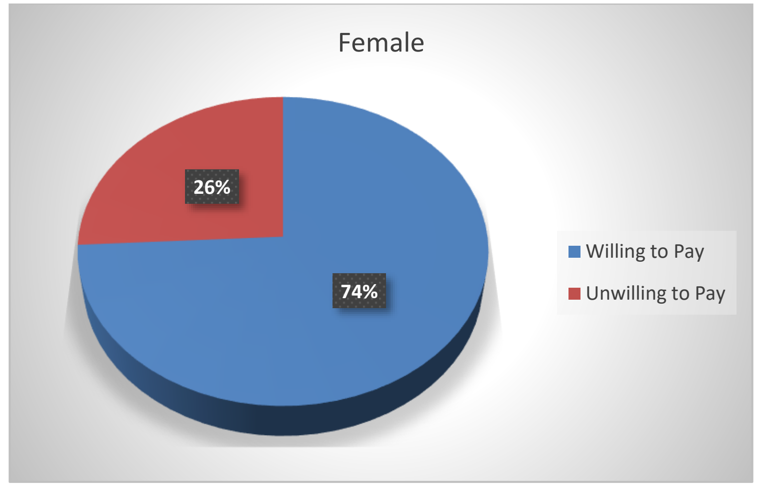
Total Sample Size: 258

"Yes" Responses: 191 (74.03%)

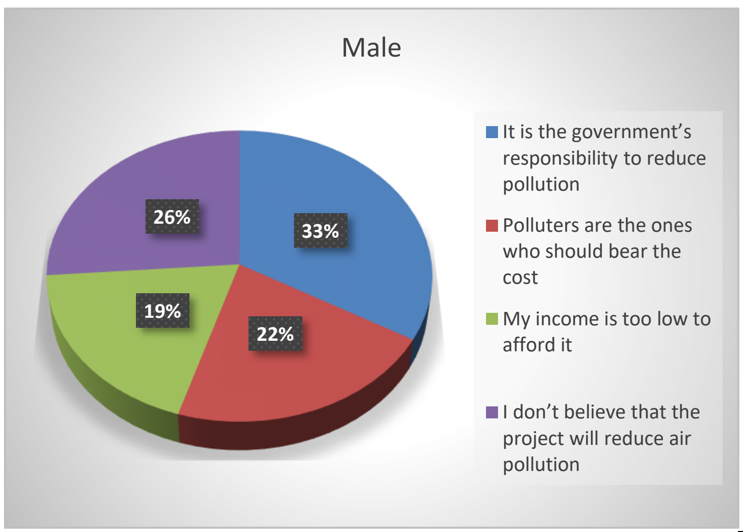
Starting Bid	100 LE (N = 66)				200 LE (N = 62)				300 LE (N = 63)			
First Response	Yes = 59 (89.39%)		No = 7 (10.61%)		Yes = 46 (74.19%)		No = 16 (25.81%)		Yes = 43 (68.25%)		No = 20 (31.75%)	
Second Bid	200 LE		50 LE		300 LE		100 LE		400 LE		200 LE	
Second Response	Yes = 40 (67.80%)	No = 19 (32.20%)	Yes = 5 (71.43%)	No = 2 (28.57%)	Yes = 29 (63.04%)	No = 17 (36.96%)	Yes = 10 (62.50%)	No = 6 (37.50%)	Yes = 29 (67.44%)	No = 14 (32.56%)	Yes = 9 (45.00%)	No = 11 (55.00%)
Follow up for "No-No" Response (open-ended)	(10, 35) Mean = 22.5 LE				(50, 50, 30, 50, 50, 20) Mean = 41.67 LE				(100, 75, 40, 75, 50, 100, 50, 100, 50, 40, 100) Mean = 70.9 LE			

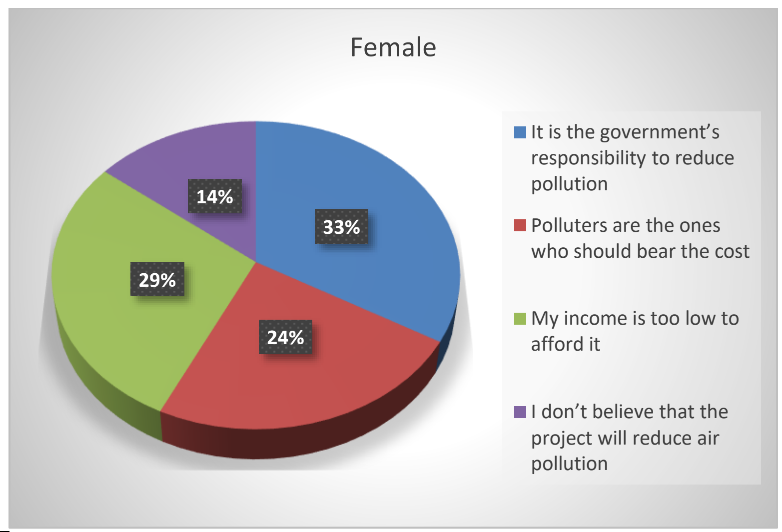
Positive WTP by Gender



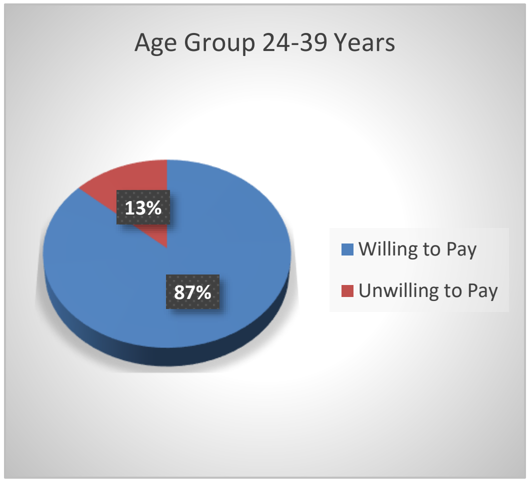


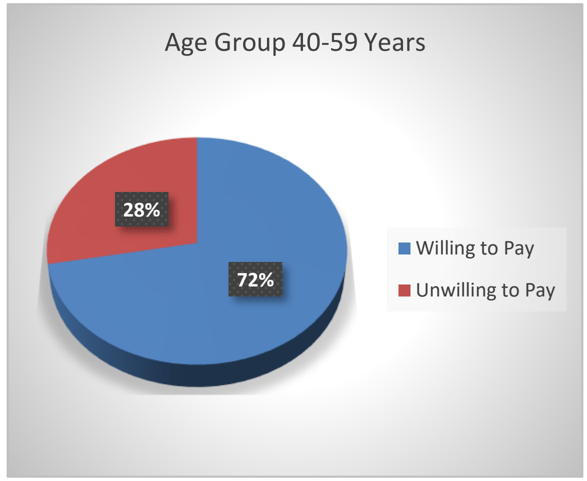
Reasons for unwilling to support the pollution control project

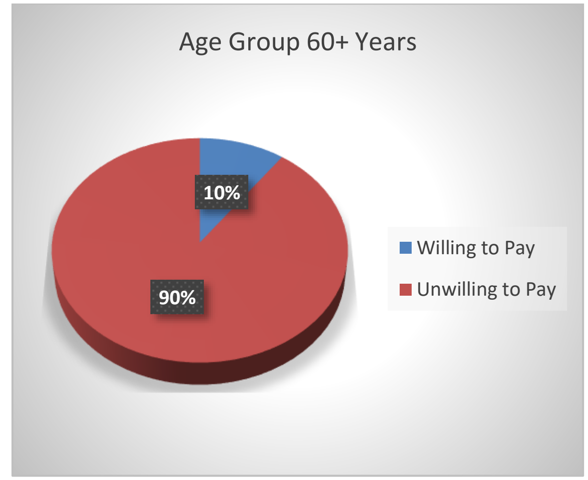




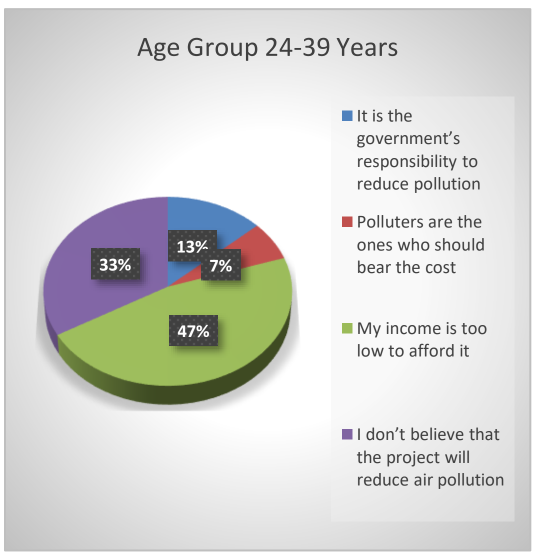
Positive WTP by Age Group

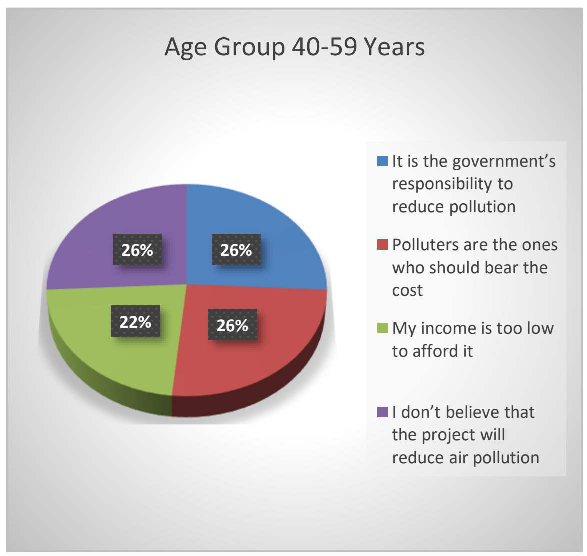


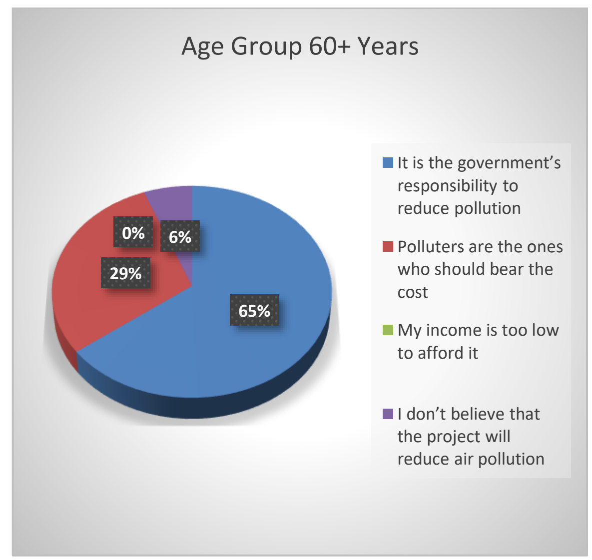




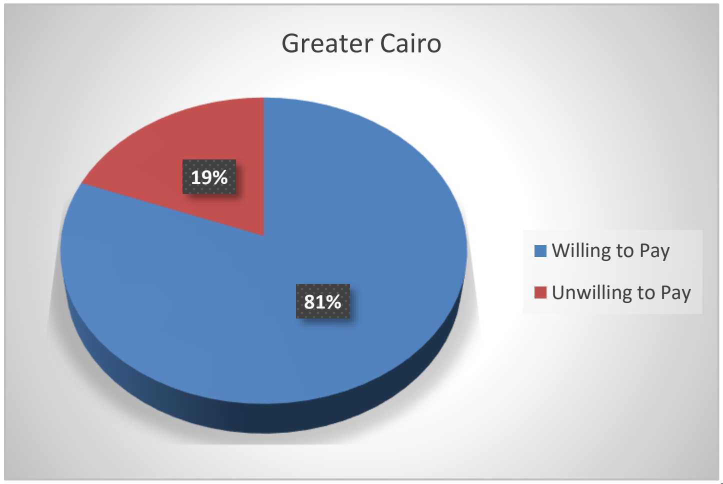
Reasons for unwilling to support the pollution control project

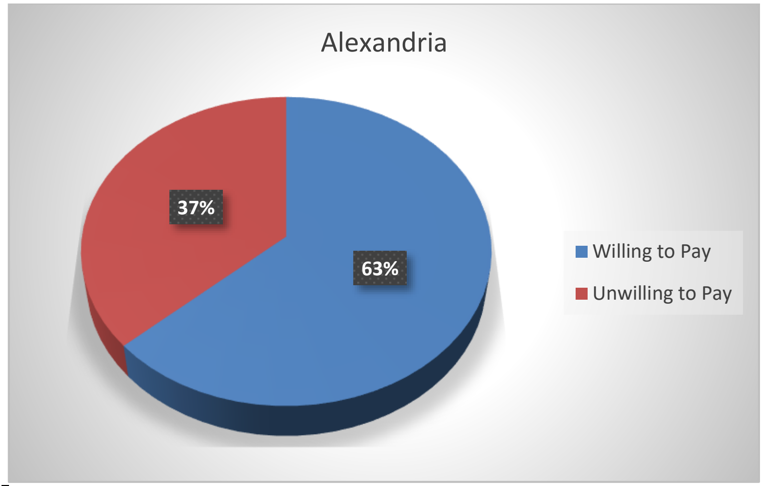




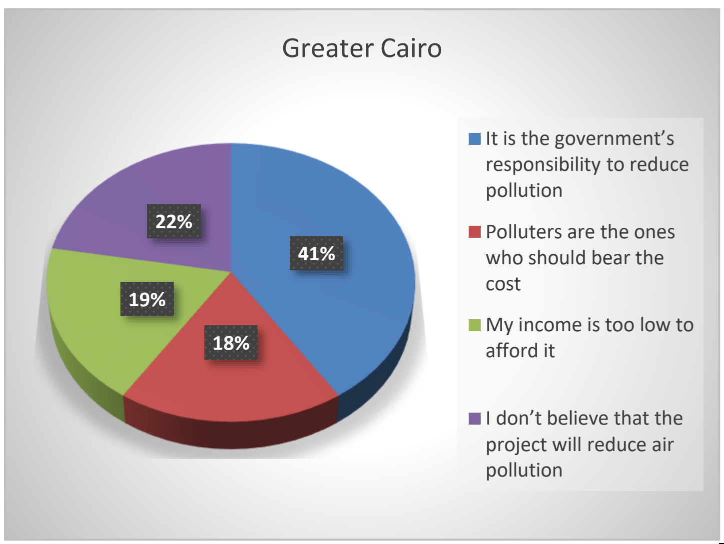


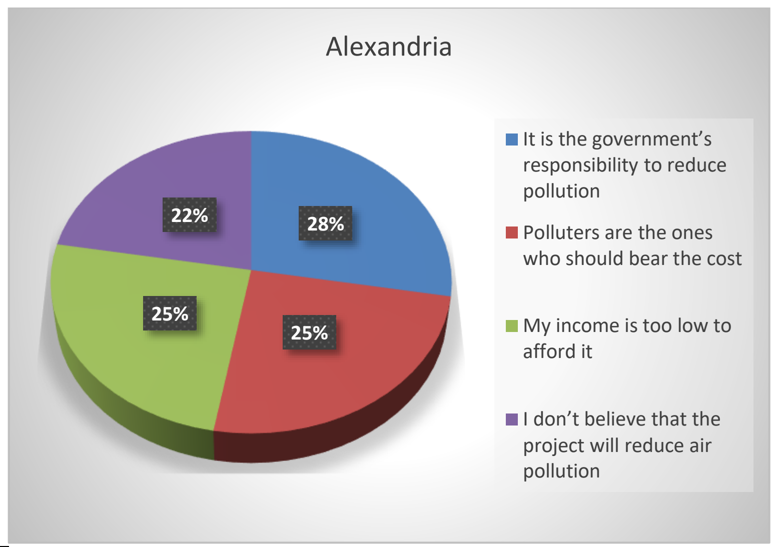
Positive WTP by Residency



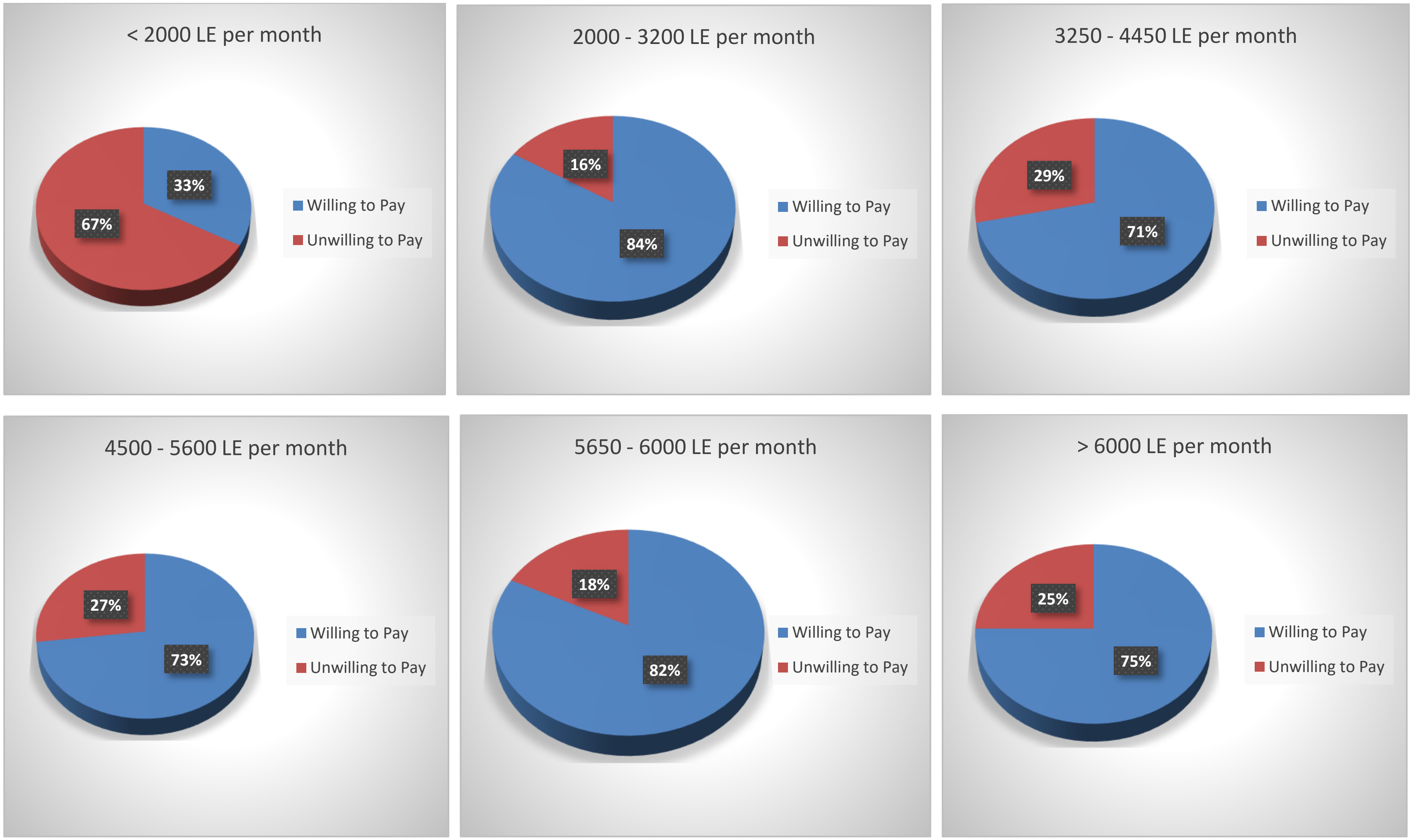


Reasons for unwilling to support the pollution control project

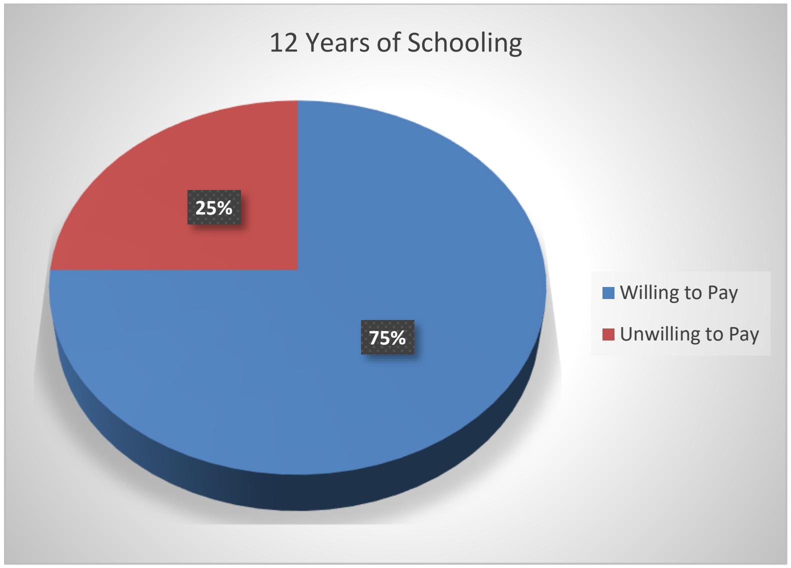


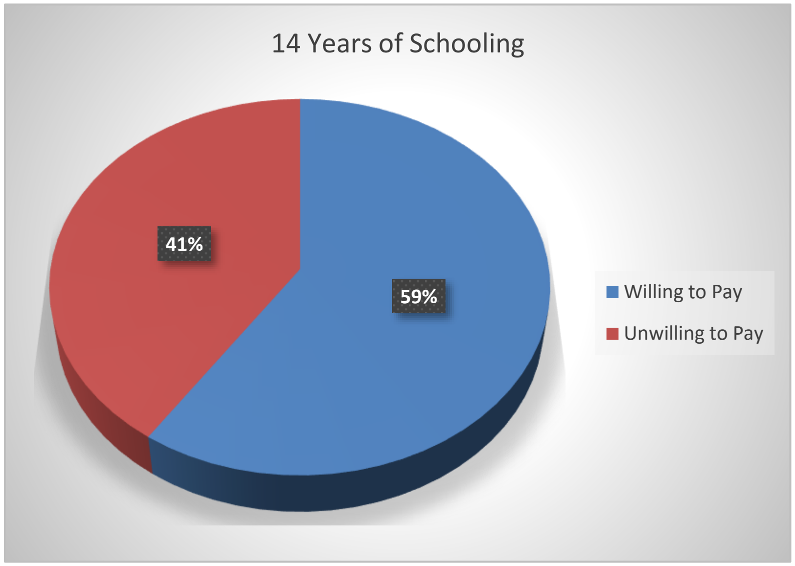


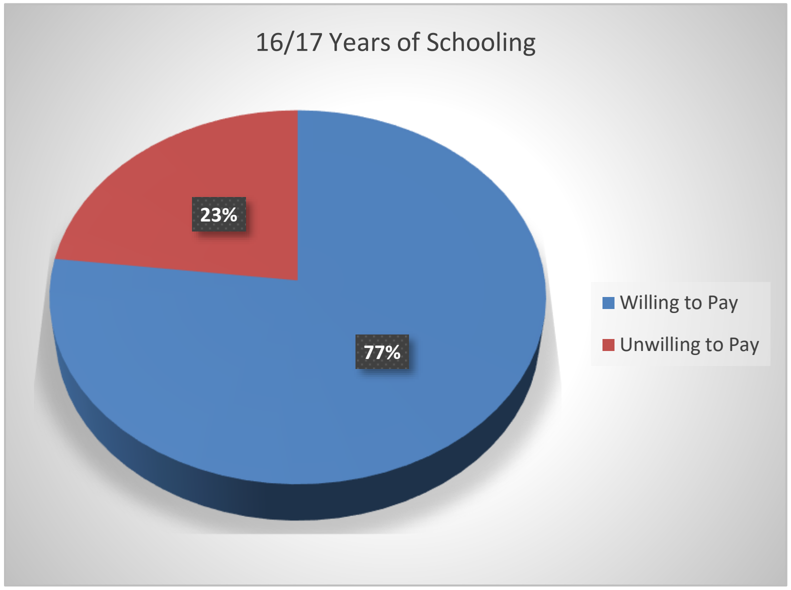
Positive WTP by Income level

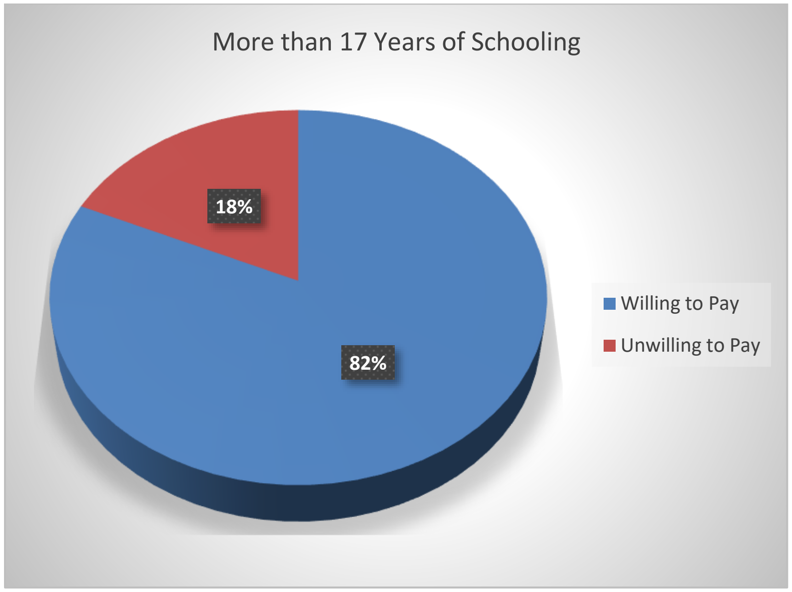


Positive WTP by Educational Level









Second Scenario: the WTP for reducing the baseline mortality risk attributed to $PM_{2.5}$ air pollution:

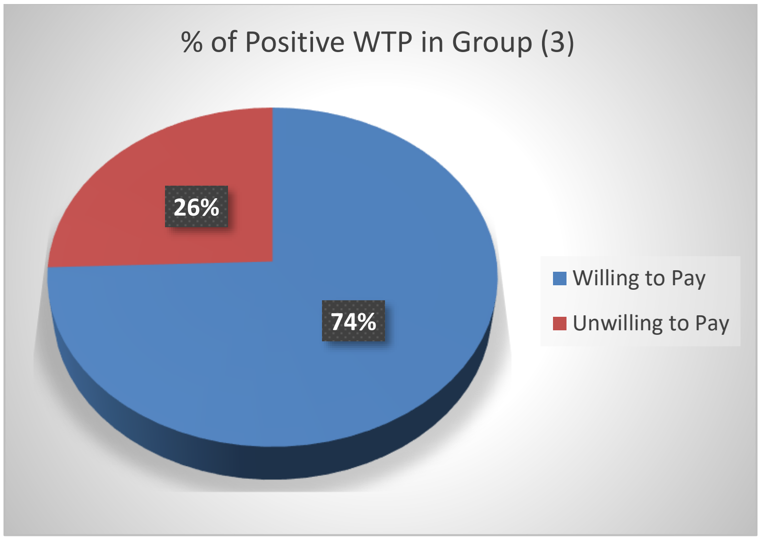
Group (3)/ Risk reduction level 10 in 10000

Air pollution ranks among the top risk factors for premature death and disability worldwide. The World Health Organization (WHO) data reveals that in 2017, ambient air pollution was responsible for about one third of deaths from lung cancer and other respiratory diseases, and from cardiovascular diseases. Suspended particulate matter air pollution (PM) is related to the most serious health impacts, especially fine particles less than 2.5 microns in size ($PM_{2.5}$) Epidemiological evidence indicates that for every 10 $\mu g/m^3$ increase in the concentration of $PM_{2.5}$, there is an increase in the overall mortality by 4%, an increase in mortality due to cardiopulmonary diseases by 6%, an increase in mortality due to lung cancer by 8%, an increase in mortality due to respiratory diseases by 0.58%, and an increase in hospitalization rate by 8%. Also, studies emphasize the link between air pollution and both bladder and liver cancer risks.

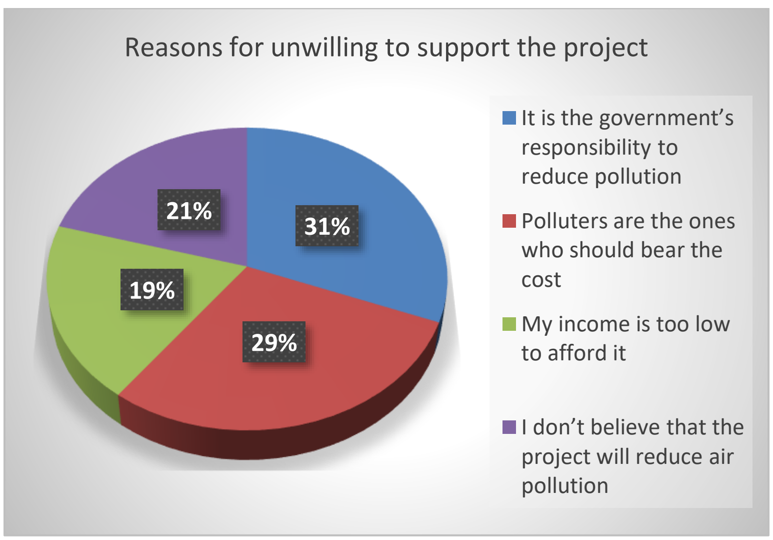
The annual average of $PM_{2.5}$ concentration in Egypt is nearly seven times higher than the guideline recommended by the World Health Organization (WHO). Egypt ranks first worldwide with respect to the prevalence of bladder cancer (causing 7.98 deaths per 100,000 individuals), and ranks fourth with respect to the prevalence of liver cancer (causing 27.42 deaths per 100,000 of individuals). Lung cancer in Egypt, is one of the most common cancers, representing between 5%-7% of all cancers. The country also is among the top ten countries in terms of death from coronary heart diseases (2016.82 deaths per 100,000 individuals).

One of the main sources of $PM_{2.5}$ pollution is industrial activity. The government can require factories to install additional air pollution control equipment in order to reduce their emissions, which would consequently reduce the pollution health risk. It is estimated that installing this pollution control equipment would reduce your mortality risk due to $PM_{2.5}$ air pollution from 1192 deaths for each 100,000 persons, to 1092 deaths for each 100,000 persons (1 in 1000 mortality risk reduction). This project will be funded through increasing sales tax rate on purchased goods.

Q.1. Implementing this regulation will increase the cost of many goods you buy. This would increase your cost of living. If your monthly living expenses increased due to this regulation, would you like the government to implement it?



Q.2. If No: Please explain why you are unwilling to support this pollution control regulation[137]:



[137] The number of "No" Responses is 70, which represents about 25.55% of the total responses within this sub-group.

Q.2. If Yes: Considering your household's monthly income and expenditures, if the additional cost to your household would be (100, 200, 300) LE per month, would you want the factories to install the pollution control equipment in order to reduce the chance that you or someone else in your household would die from exposure to ambient particulate matter?

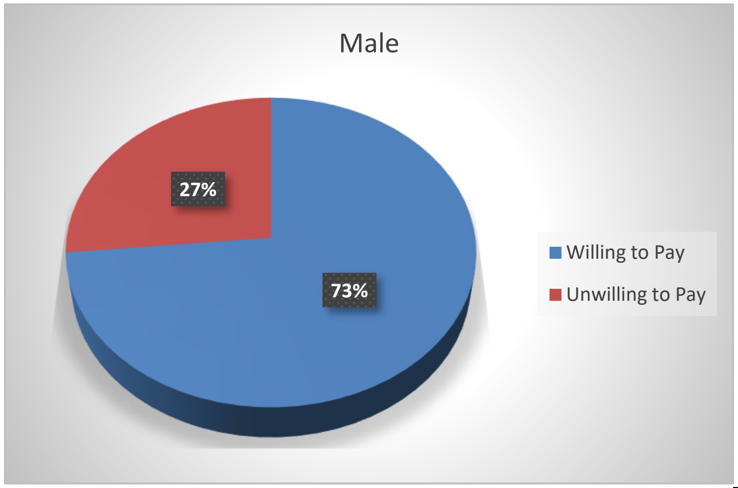
Q.3. If Yes: If the prices of goods increased more than anticipated as a result of implementing this regulation, and now the additional cost to your household would be (200, 300, 400) LE per month, would you still support this regulation? Please notice that if you accept, you will lose some of your income that you could have spent on other things costing the same amount.

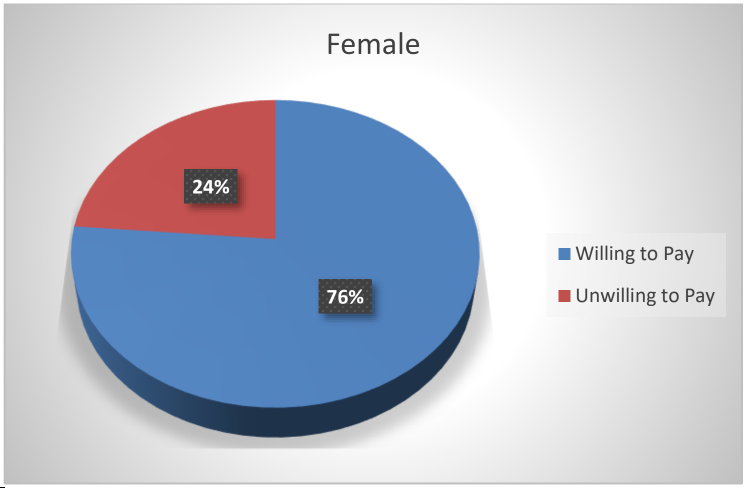
Q.3. If No: If the prices of goods increased less than anticipated as a result of implementing this regulation, and now the additional cost to your household would be only (50, 100, 200) LE per month, would you support this regulation?

Q.4. Considering your household's monthly income and expenditures, what is the maximum increase in your monthly expenses that you would accept in order to support this regulation?

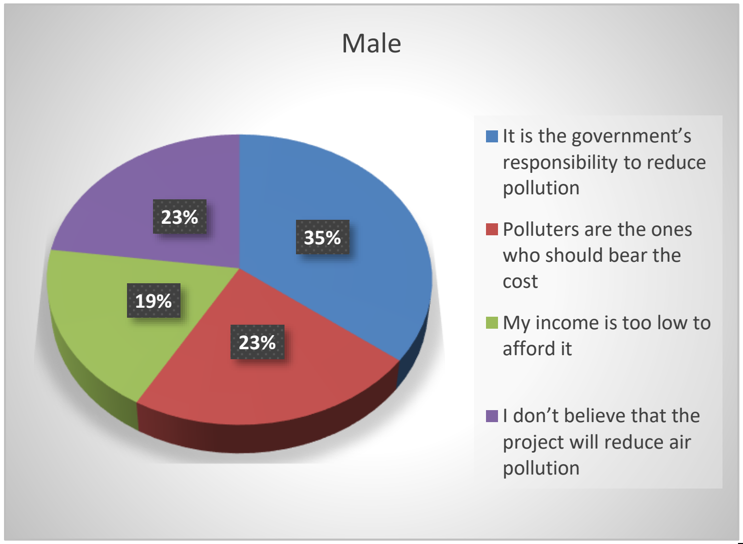
Total Sample Size: 274 **"Yes" Responses: 204 (74.45%)**												
Starting Bid	100 LE (N = 59)				200 LE (N = 83)				300 LE (N = 62)			
First Response	Yes = 54 (91.53%)		No = 5 (8.47%)		Yes = 57 (68.67%)		No = 26 (31.33%)		Yes = 42 (67.74%)		No = 20 (32.26%)	
Second Bid	200 LE		50 LE		300 LE		100 LE		400 LE		200 LE	
Second Response	Yes = 33 (61.11%)	No = 21 (38.89%)	Yes = 2 (40%)	No = 3 (60%)	Yes = 37 (64.91%)	No = 20 (35.09%)	Yes = 12 (46.15%)	No = 14 (53.85%)	Yes = 24 (57.14%)	No = 18 (42.86%)	Yes = 4 (20%)	No = 16 (80%)
Follow up for "No-No" Response (open-ended)	(49, 10, 30) Mean = 29.6 LE				(75, 50, 50, 50, 20, 50, 50, 15, 5, 22, 50, 1, 50, 50) Mean = 38.43 LE				(100, 50, 100, 100, 100, 50, 100, 100, 5 0, 199, 100, 18,10, 50, 0, 150) Mean = 79.8 LE			

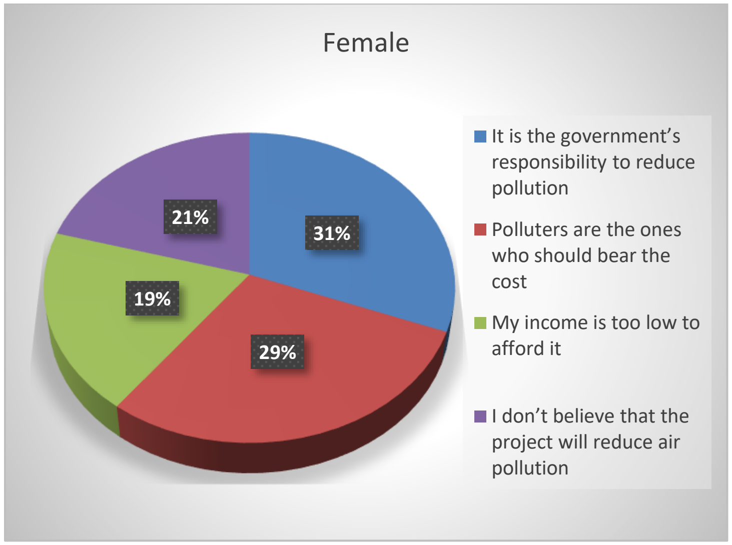
Positive WTP by Gender



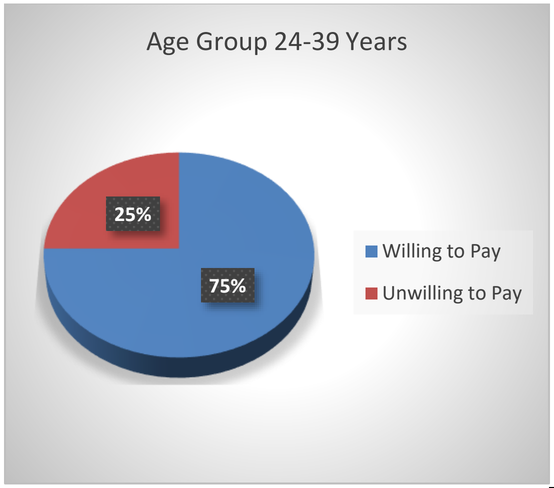


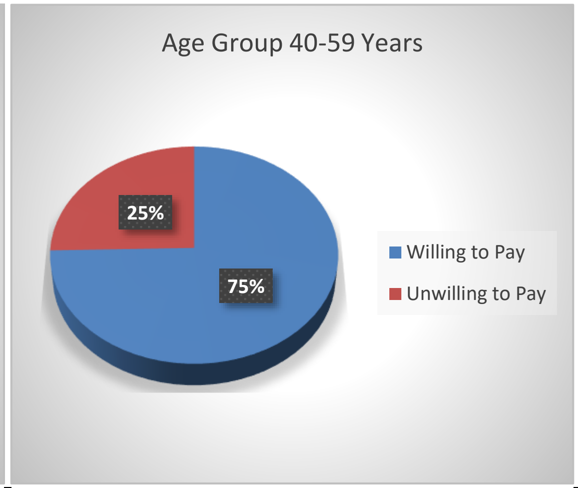
Reasons for unwilling to support the pollution control project

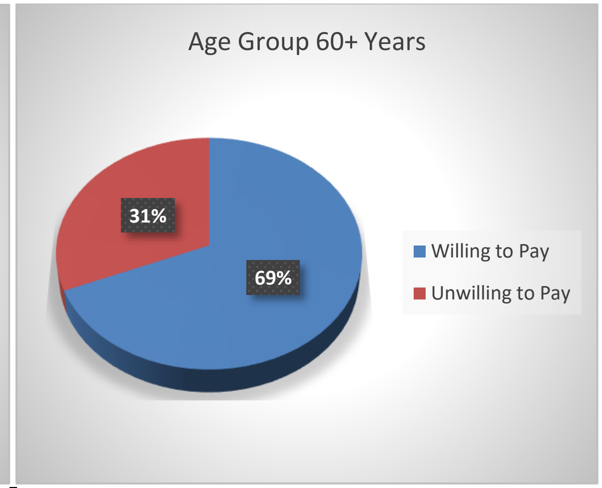




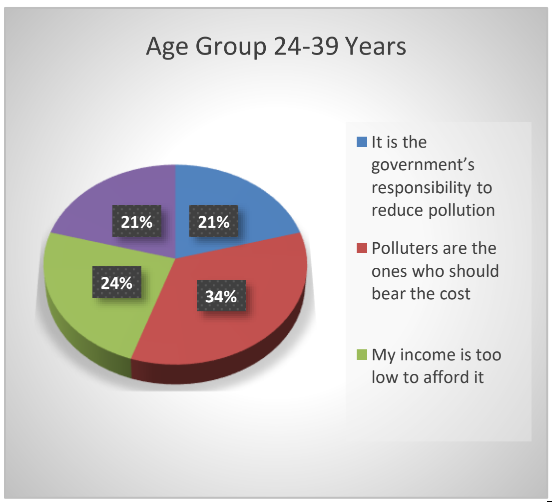
Positive WTP by Age Group

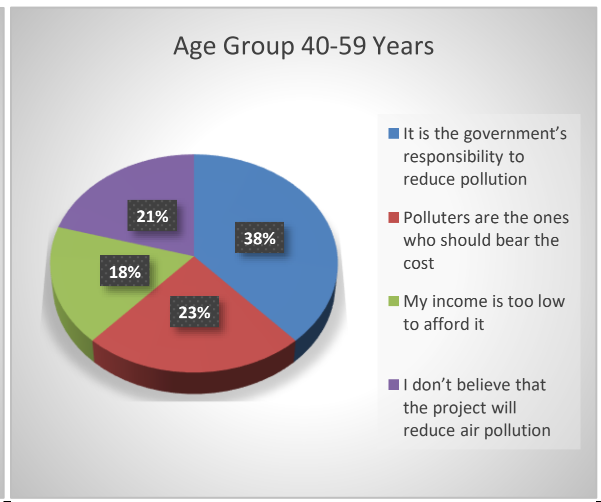


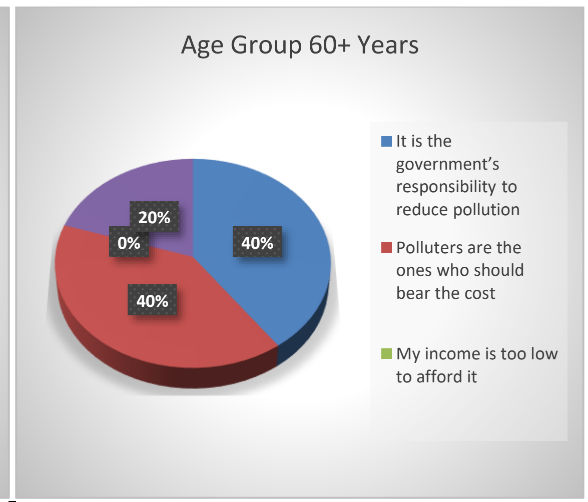




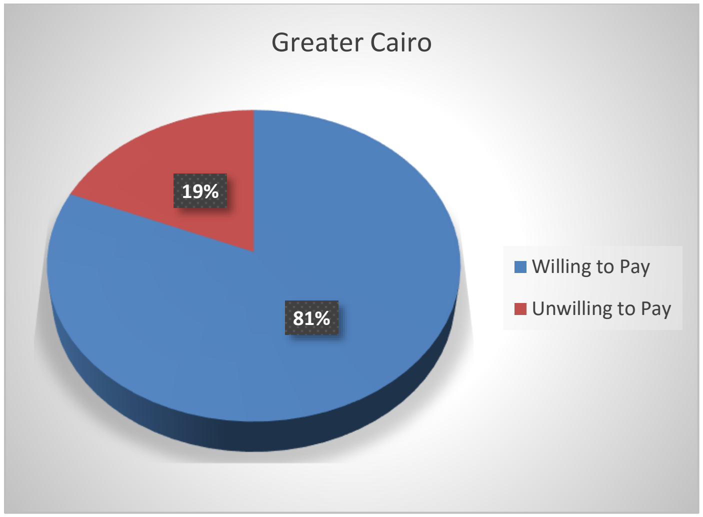
Reasons for unwilling to support the pollution control project

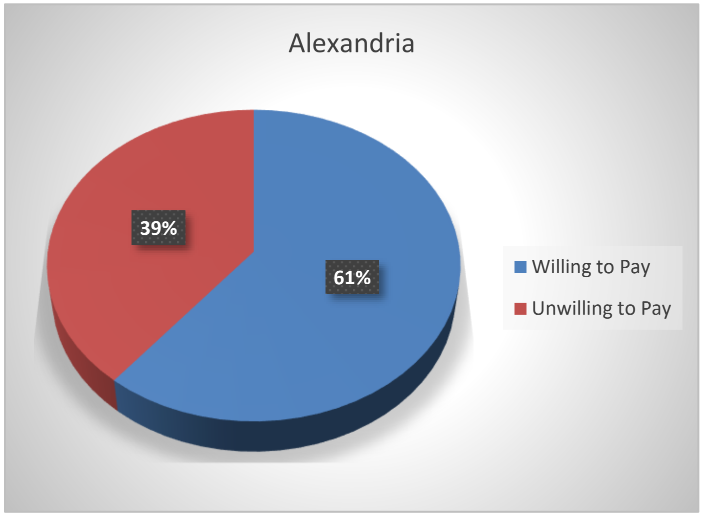




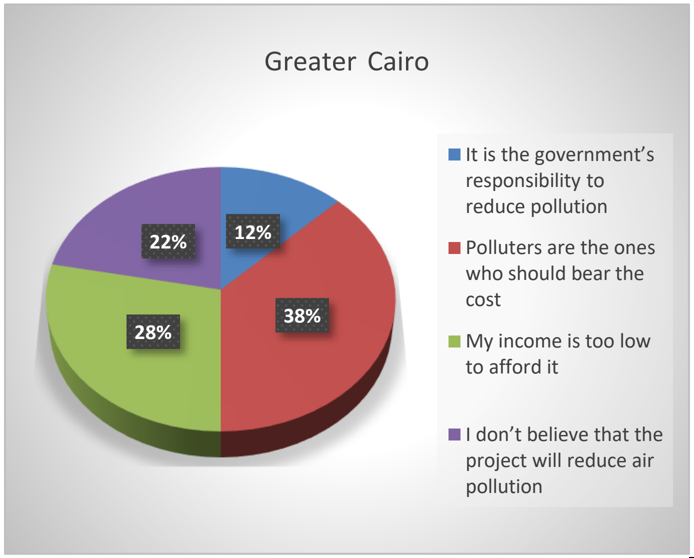


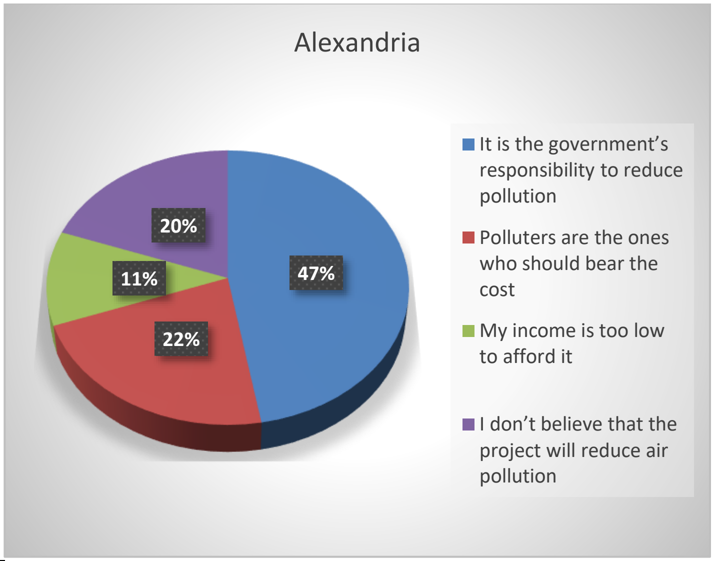
Positive WTP by Residency



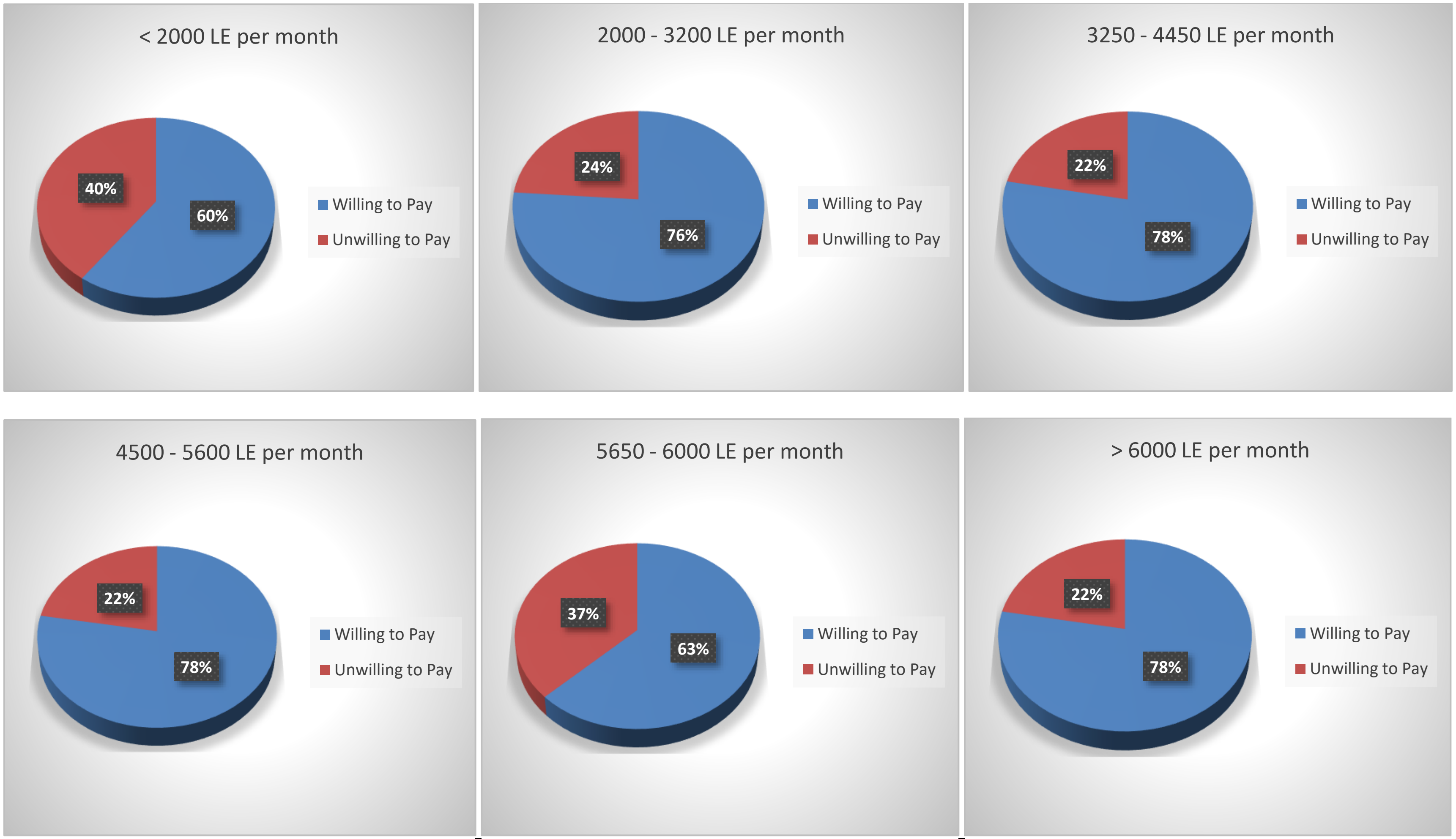


Reasons for unwilling to support the pollution control project

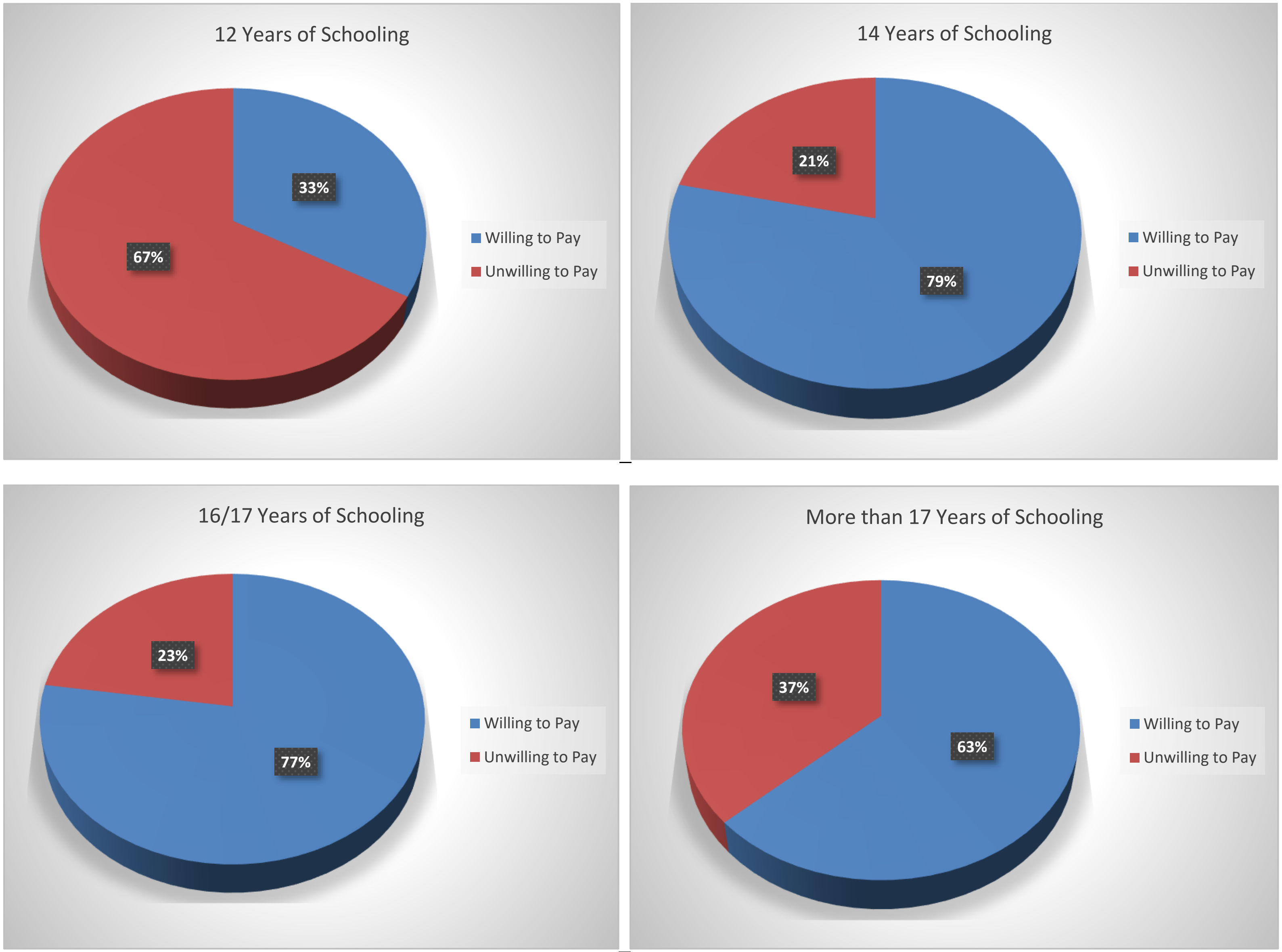




Positive WTP by Income Level



Positive WTP by Educational Level



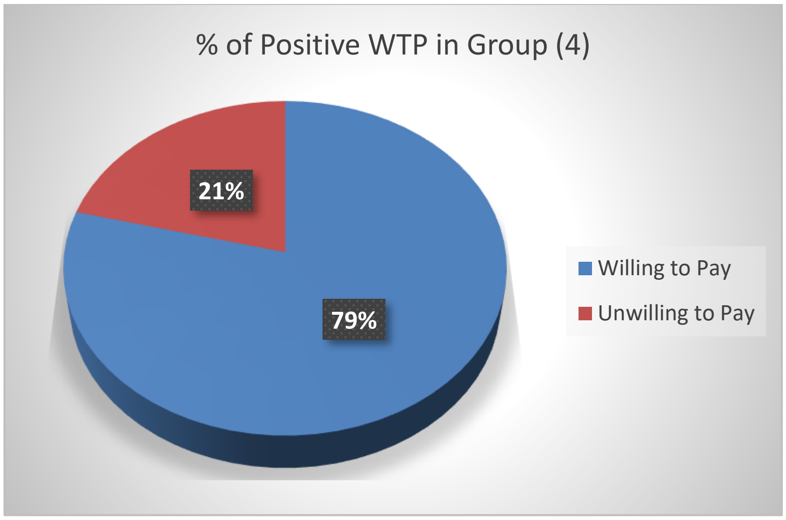
Group (4)/ Risk reduction level 5 in 10000

Air pollution ranks among the top risk factors for premature death and disability worldwide. The World Health Organization (WHO) data reveals that in 2017, ambient air pollution was responsible for about one third of deaths from lung cancer and other respiratory diseases, and from cardiovascular diseases. Suspended particulate matter air pollution (PM) is related to the most serious health impacts, especially fine particles less than 2.5 microns in size ($PM_{2.5}$) Epidemiological evidence indicates that for every 10 $\mu g/m^3$ increase in the concentration of $PM_{2.5}$, there is an increase in the overall mortality by 4%, an increase in mortality due to cardiopulmonary diseases by 6%, an increase in mortality due to lung cancer by 8%, an increase in mortality due to respiratory diseases by 0.58%, and an increase in hospitalization rate by 8%. Also, studies emphasize the link between air pollution and both bladder and liver cancer risks.

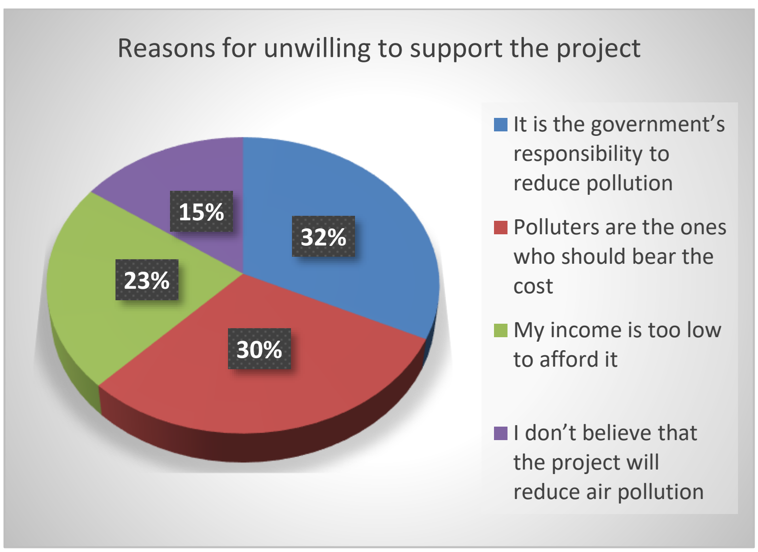
The annual average of $PM_{2.5}$ concentration in Egypt is nearly seven times higher than the guideline recommended by the World Health Organization (WHO). Egypt ranks first worldwide with respect to the prevalence of bladder cancer (causing 7.98 deaths per 100,000 individuals), and ranks fourth with respect to the prevalence of liver cancer (causing 27.42 deaths per 100,000 of individuals). Lung cancer in Egypt, is one of the most common cancers, representing between 5%-7% of all cancers. The country also is among the top ten countries in terms of death from coronary heart diseases (2016.82 deaths per 100,000 individuals).

One of the main sources of $PM_{2.5}$ pollution is industrial activity. The government can require factories to install additional air pollution control equipment in order to reduce their emissions, which would consequently reduce the pollution health risk. It is estimated that installing this pollution control equipment would reduce your mortality risk due to $PM_{2.5}$ air pollution from 1192 deaths for each 100,000 persons, to 1142 deaths for each100,000 persons (5 in 10000 mortality risk reduction). This project will be funded through increasing sales tax rate on purchased goods.

Q.1. Implementing this regulation will increase the cost of many goods you buy. This would increase your cost of living. If your monthly living expenses increased due to this regulation, would you like the government to implement it?



Q.2. If No: Please explain why you are unwilling to support this pollution control regulation[138]:



[138] The number of "No" Responses is 54, which represents about 21% of the total responses within this sub-group.

Q.2. If Yes: Considering your household’s monthly income and expenditures, if the additional cost to your household would be (100, 200, 300) LE per month, would you want the factories to install the pollution control equipment in order to reduce the chance that you or someone else in your household would die from exposure to ambient particulate matter?

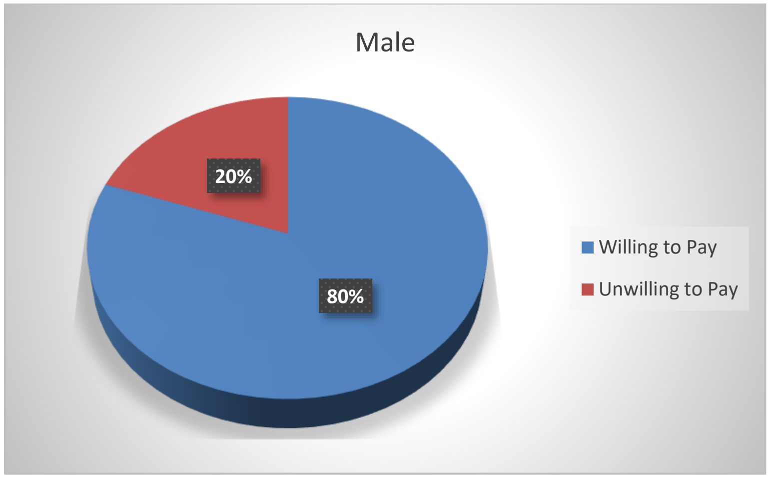
Q.3. If Yes: If the prices of goods increased more than anticipated as a result of implementing this regulation, and now the additional cost to your household would be (200, 300, 400) LE per month, would you still support this regulation? Please notice that if you accept, you will lose some of your income that you could have spent on other things costing the same amount.

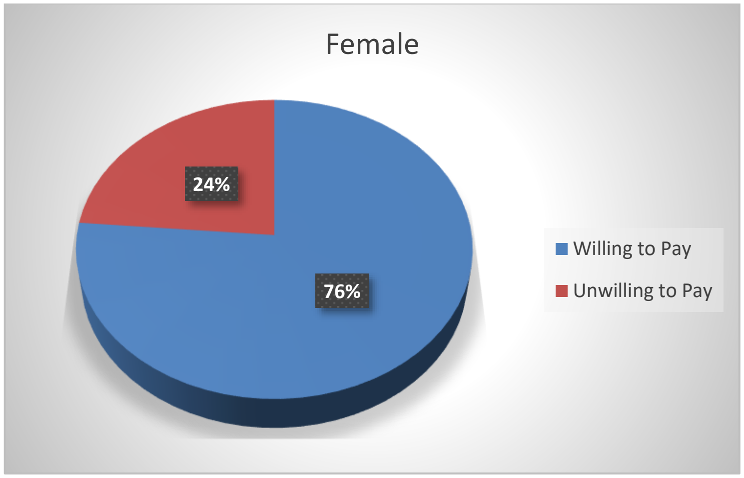
Q.3. If No: If the prices of goods increased less than anticipated as a result of implementing this regulation, and now the additional cost to your household would be only (50, 100, 200) LE per month, would you support this regulation?

Q.4. Considering your household's monthly income and expenditures, what is the maximum increase in your monthly expenses that you would accept in order to support this regulation?

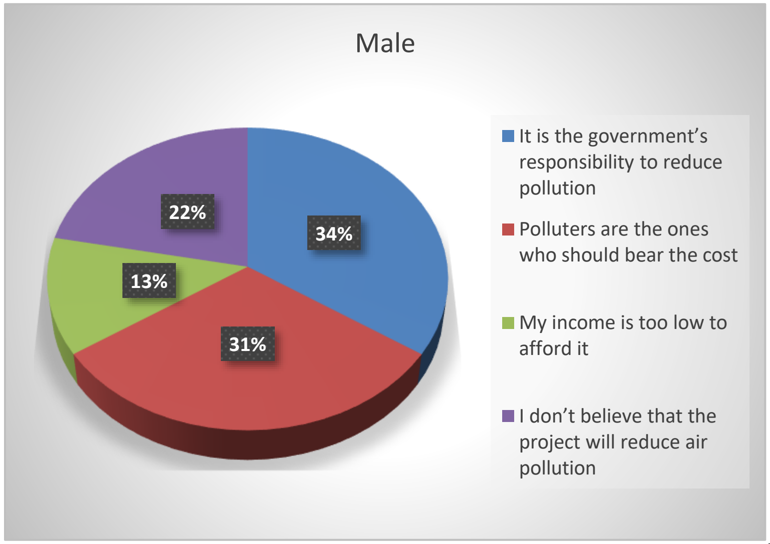
Total Sample Size: 257 **“Yes” Responses: 203 (79%)**												
Starting Bid	100 LE (N = 74)				200 LE (N = 64)				300 LE (N = 65)			
First Response	Yes = 69 (93.24%)		No = 5 (6.76%)		Yes = 48 (75%)		No = 16 (25%)		Yes = 45 (69.23%)		No = 20 (30.77%)	
Second Bid	200 LE		50 LE		300 LE		100 LE		400 LE		200 LE	
Second Response	Yes = 45 (65.2%)	No = 24 (34.8%)	Yes = 3 (60%)	No = 2 (40%)	Yes = 31 (64.6%)	No = 17 (35.4%)	Yes = 12 (75%)	No = 4 (25%)	Yes = 27 (60%)	No = 18 (40%)	Yes = 9 (45%)	No = 11 (55%)
Follow up for “No-No” Response (open-ended)	(40, 20) Mean = 30 LE				(50, 30, 20, 75) Mean = 43.75 LE				(150, 20, 100, 75, 50, 100, 50, 50, 100, 150, 50) Mean = 81.36 LE			

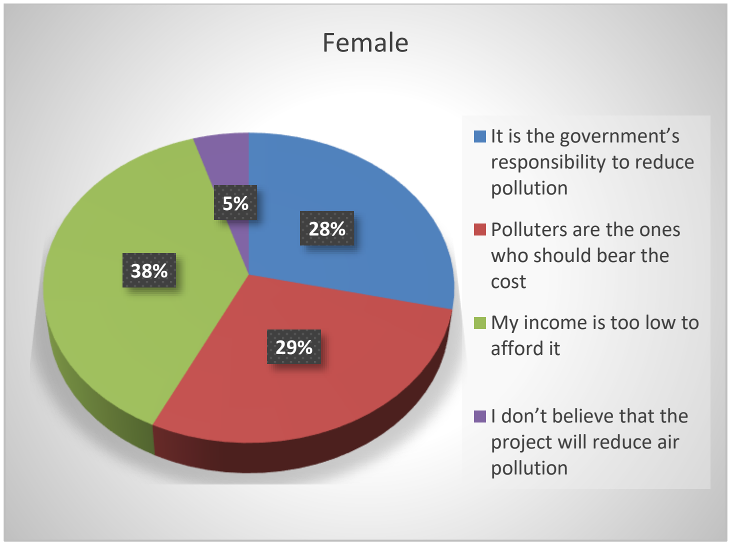
Positive WTP by Gender



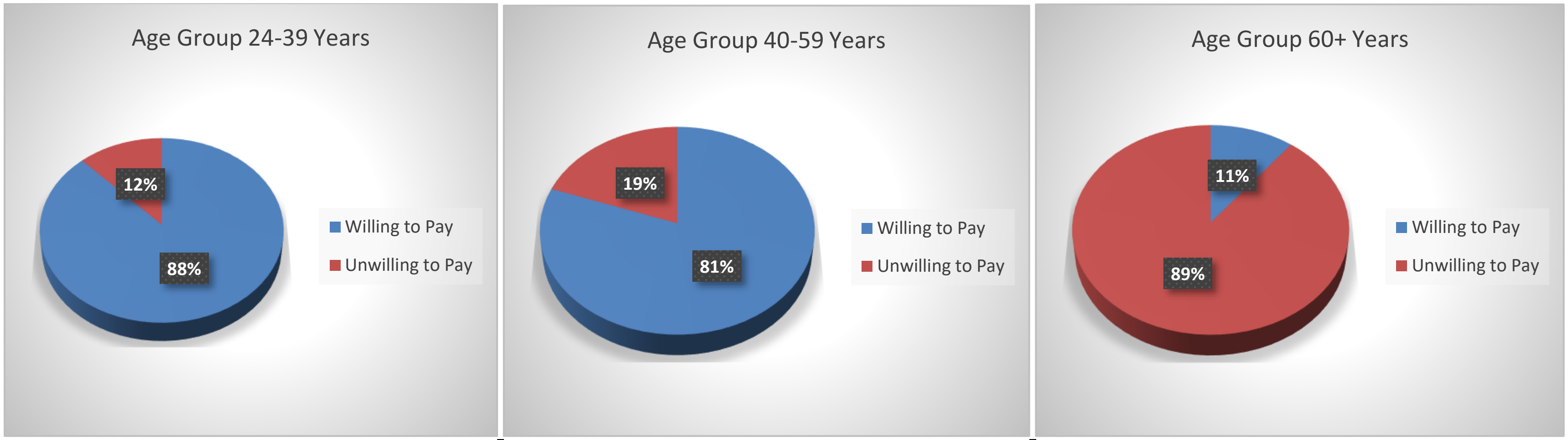


Reasons for unwilling to support the pollution control project

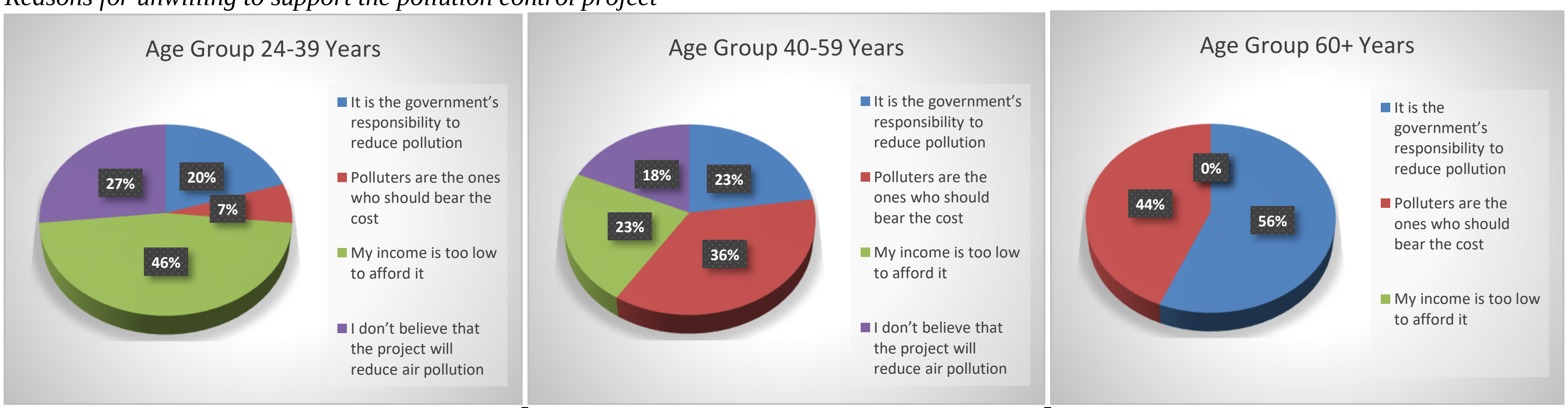




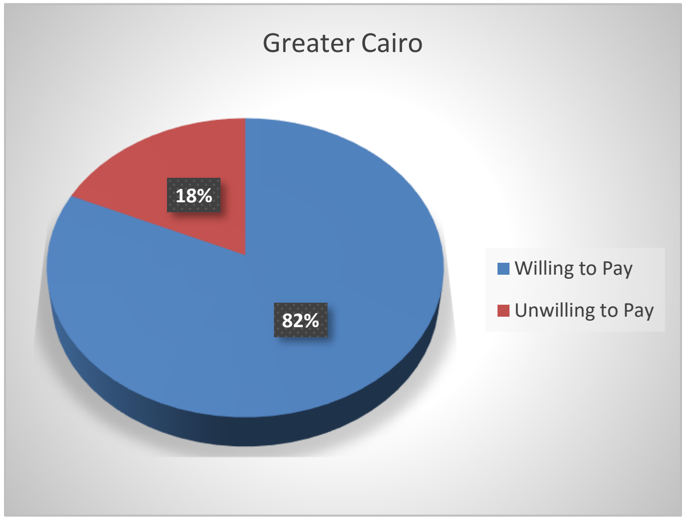
Positive WTP by Age Group

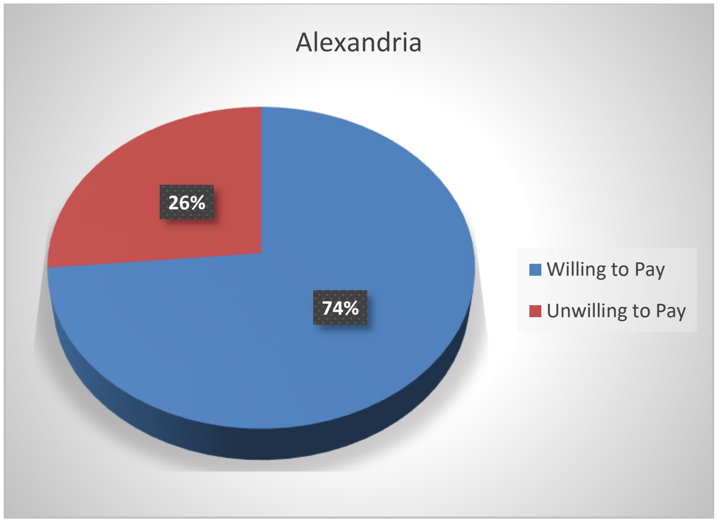


Reasons for unwilling to support the pollution control project

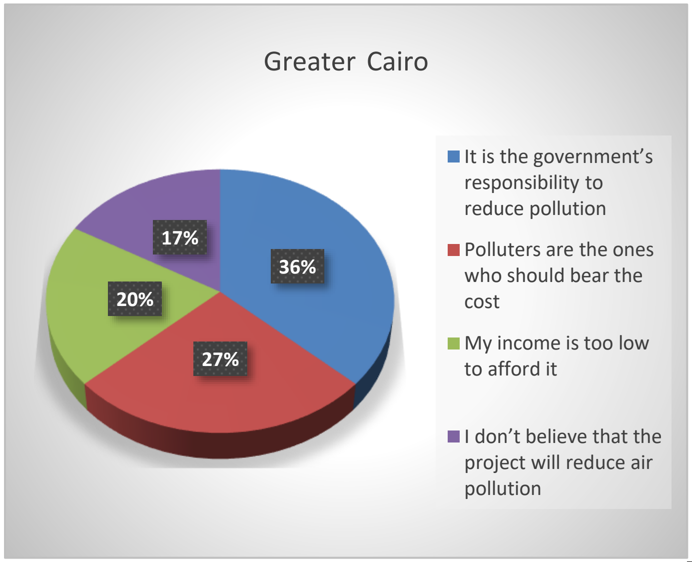


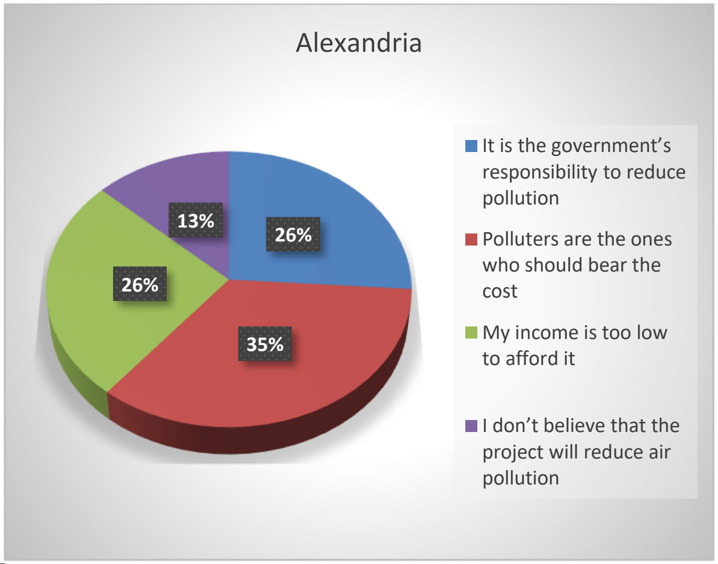
Positive WTP by Residency



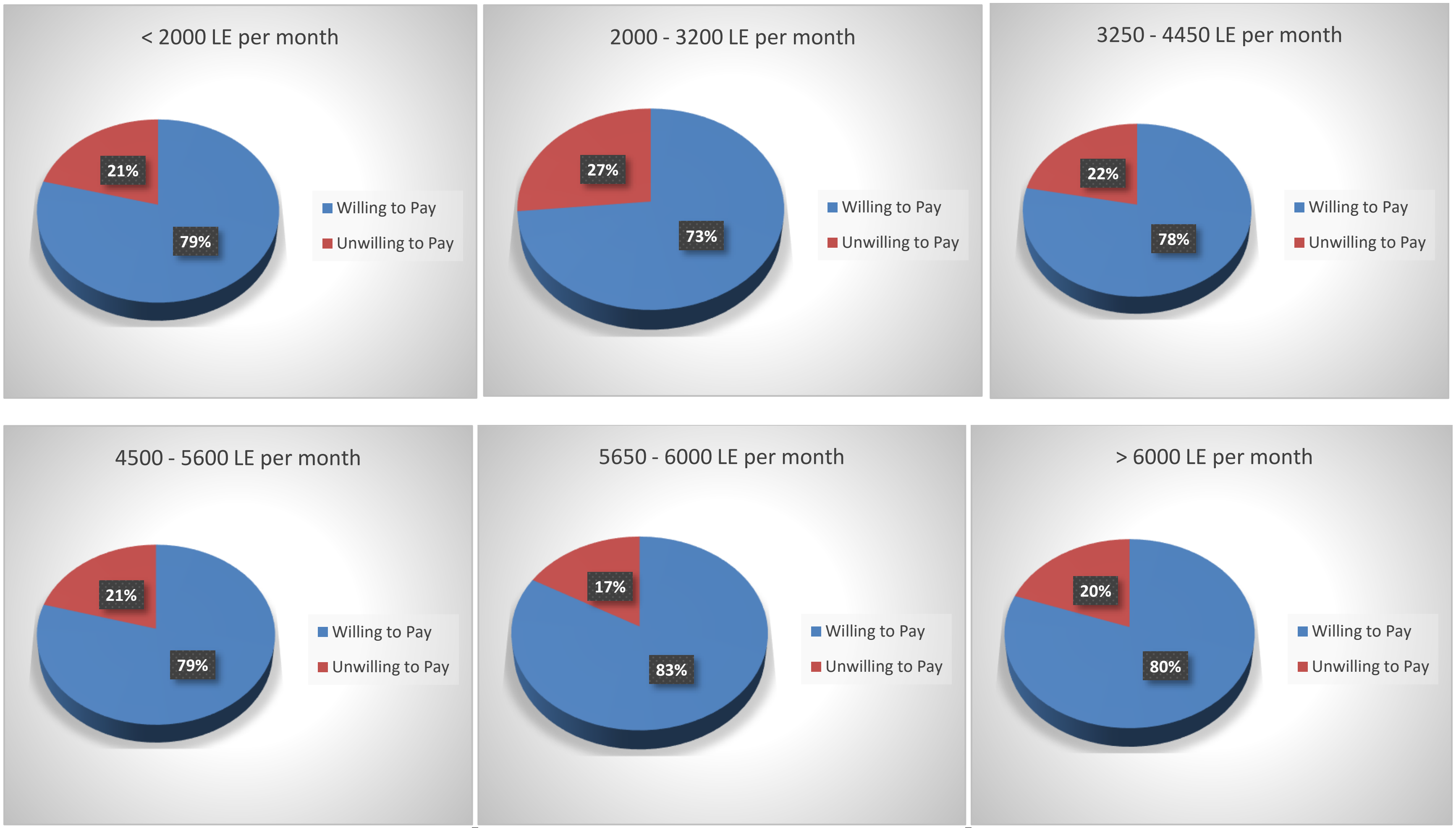


Reasons for unwilling to support the pollution control project

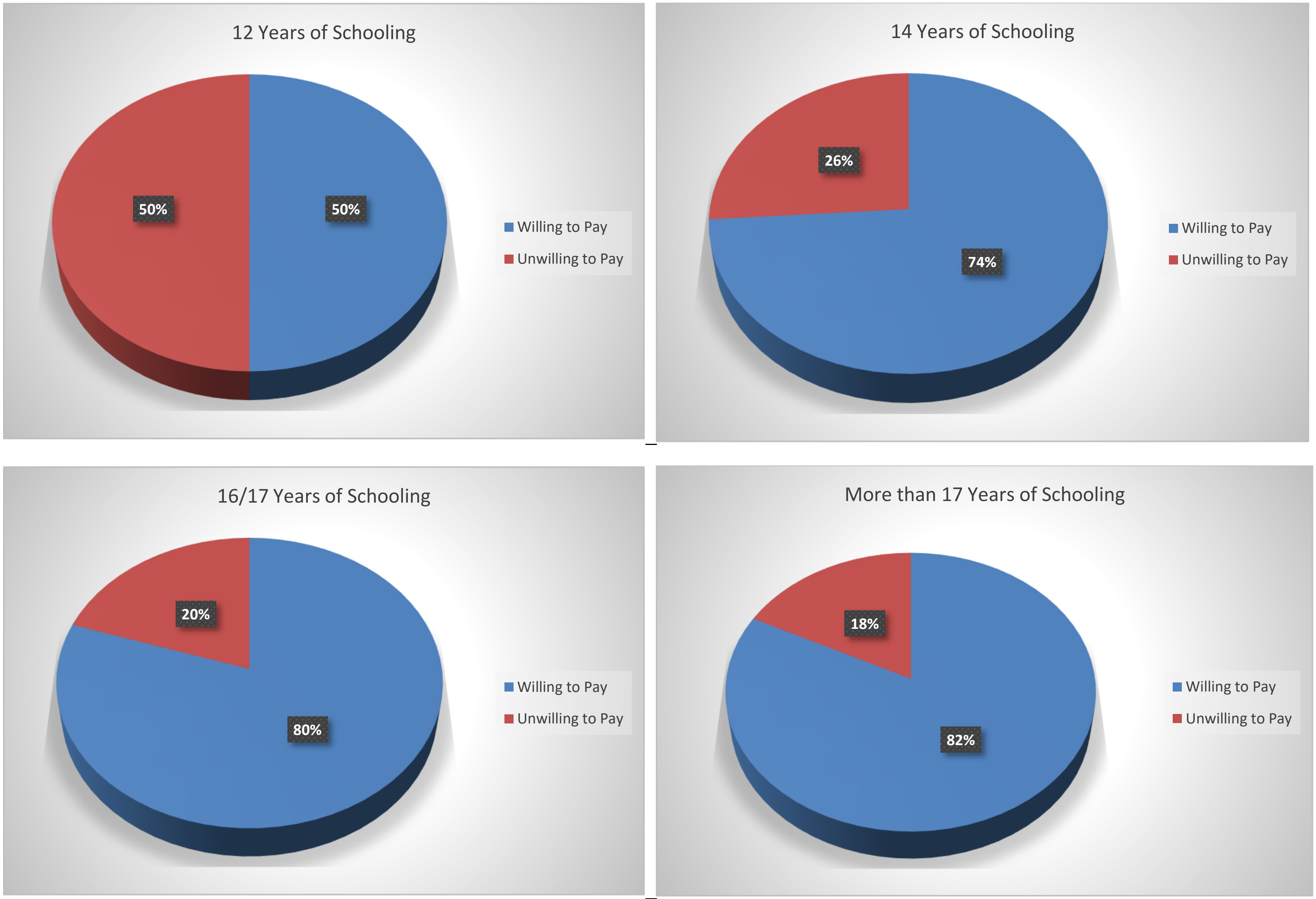




Positive WTP by Income Level



Positive WTP by Educational Level

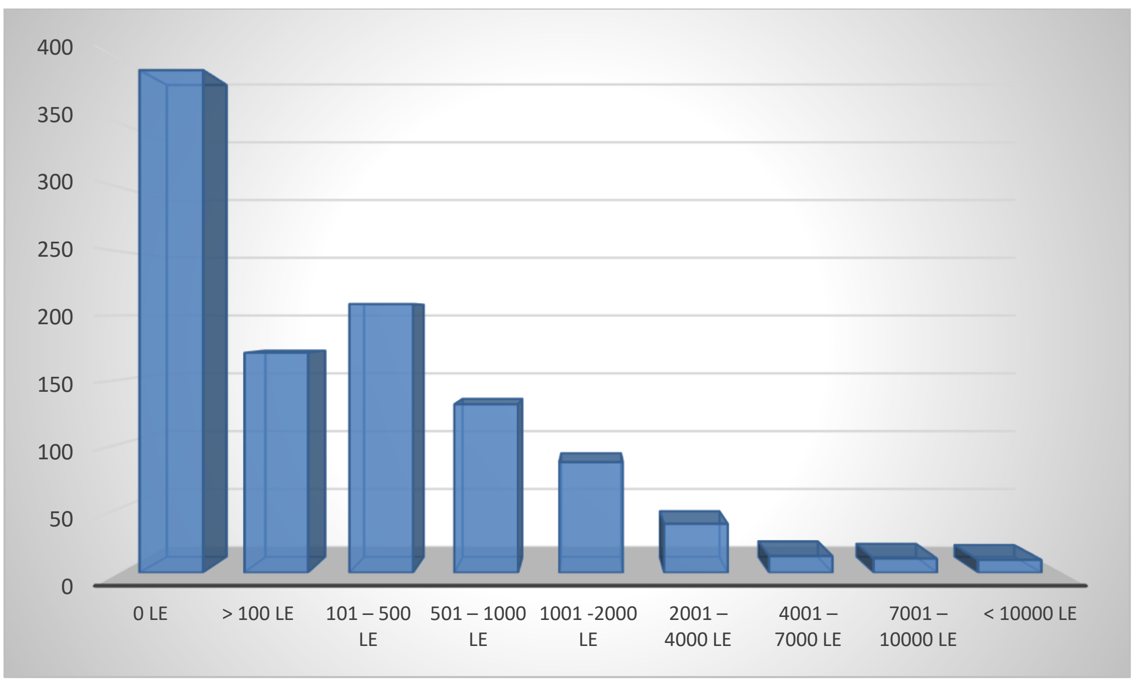


Part (5): Health and Economic burden of air pollution:

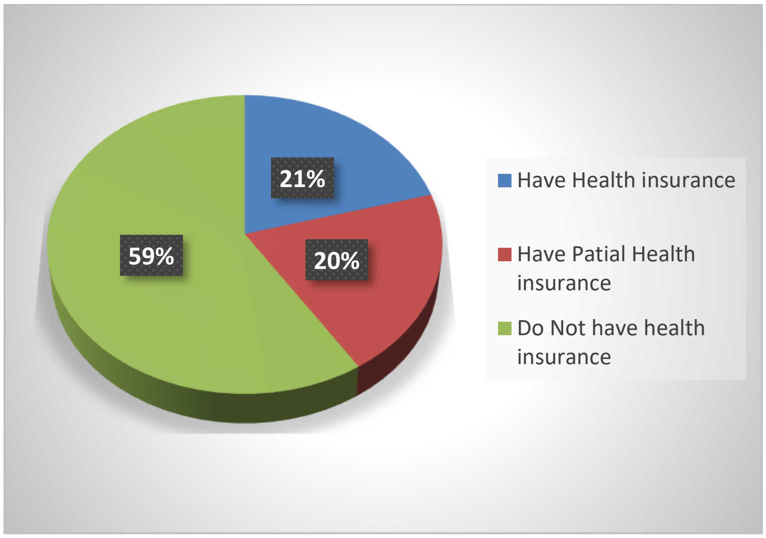
1. Do you or any one of your household members suffer from the following diseases (please indicate the number of sufferers, if any):

Diseases	0	1	2	3+	Total
Respiratory diseases (Bronchial asthma, Chronic obstructive pulmonary disease)	825	183	40	12	1060
Cardiovascular diseases (Angina, Myocardial Infarction)	850	163	36	11	1060
Cerebrovascular disease (Stroke)	959	81	12	8	1060
Lung cancer	1003	37	10	10	1060
Bladder cancer	1025	18	6	11	1060
Kidney diseases	951	82	11	16	1060
Liver diseases	907	123	15	15	1060

2. Please state your typical monthly health expenditures spent on treating these diseases:



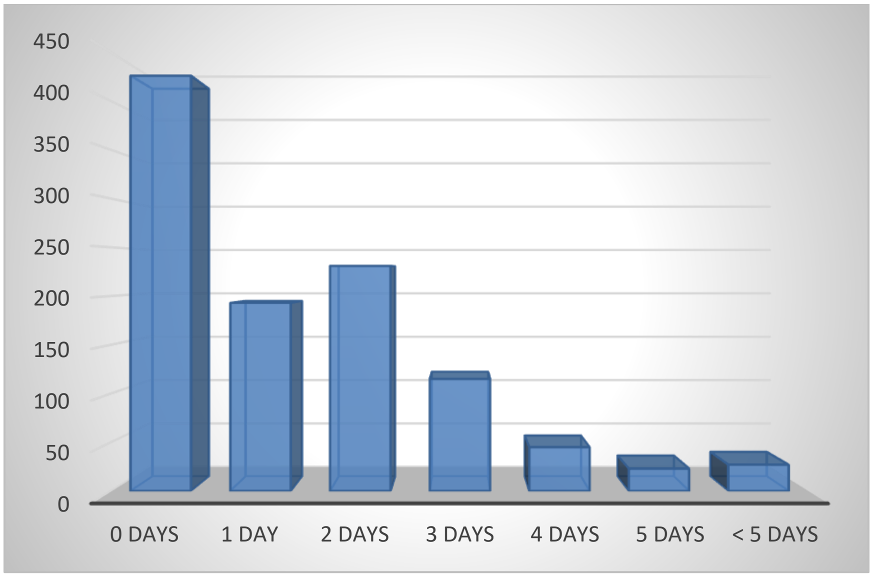
3. How do you pay for your medical expenses?



Partial health insurance (the percentage of coverage, e.g. 10%):

% of Coverage	% of Respondents	No. of Respondents	% of Coverage	% of Respondents	No. of Respondents
10	1.40%	3	65	0.47%	1
20	3.27%	7	70	7.48%	16
25	5.61%	12	75	7.01%	15
30	3.27%	7	80	5.14%	11
33	0.47%	1	85	0.47%	1
35	0.93%	2	90	3.74%	8
40	4.21%	9	98	0.47%	1
50	45.33%	97	99	1.40%	3
60	5.14%	11			

4. Please state the typical monthly number of absence days due to sickness and illness from these Diseases:



5. Do you have an air purifier installed at your home?

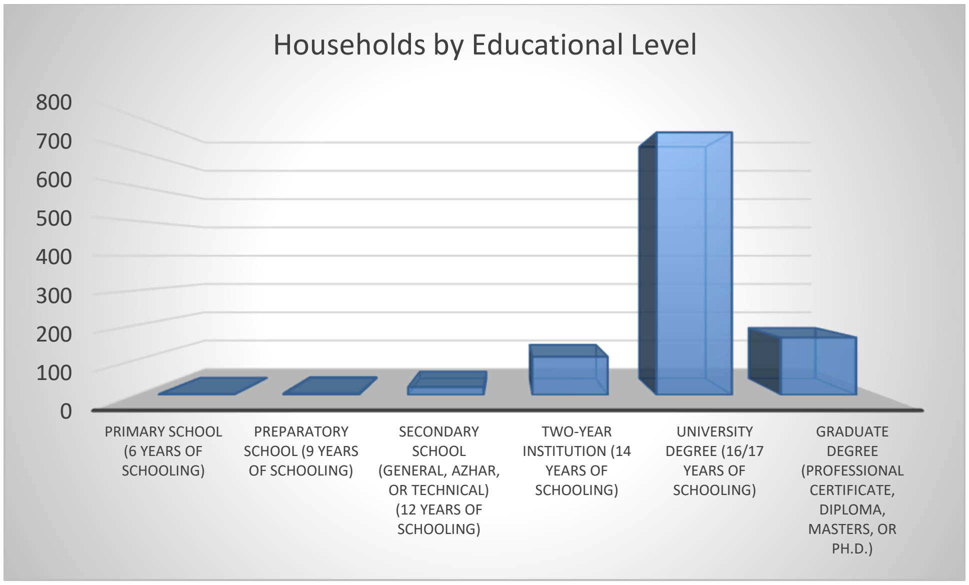
Yes	108
No	952
Total	1060

If Yes, approximately, how much do you pay for using a air purifier per month?

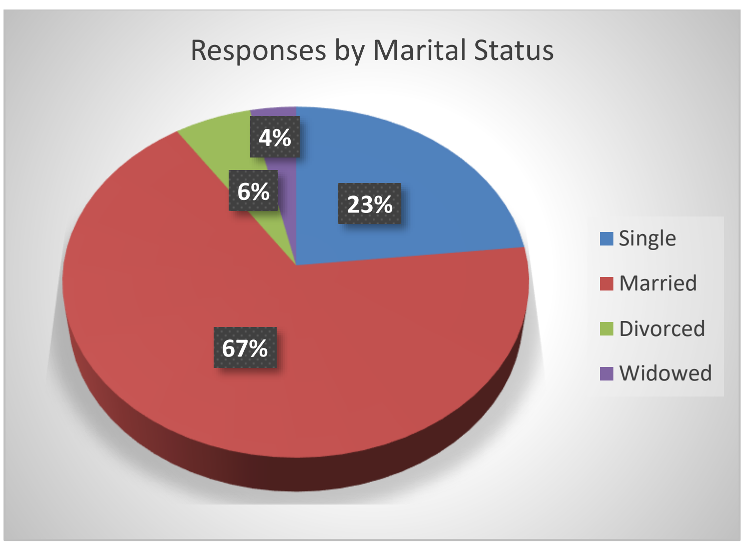
LE	%	No. Respondents	LE	%	No. Respondents
100	3.72%	4	1000	10.19%	11
200	4.63%	5	1200	5.56%	6
300	7.41%	8	1300	0.93%	1
400	3.70%	4	1350	0.93%	1
500	6.48%	7	1400	1.85%	2
600	4.63%	5	1500	2.78%	3
700	8.33%	9	1700	2.78%	3
800	16.67%	18	1800	1.85%	2
850	3.70%	4	2000	4.63%	5
900	4.63%	5	3000	0.93%	1
950	2.78%	3	4000	0.93%	1

Part (6): Demographic Characteristics (2):

1. Please indicate your highest educational level:



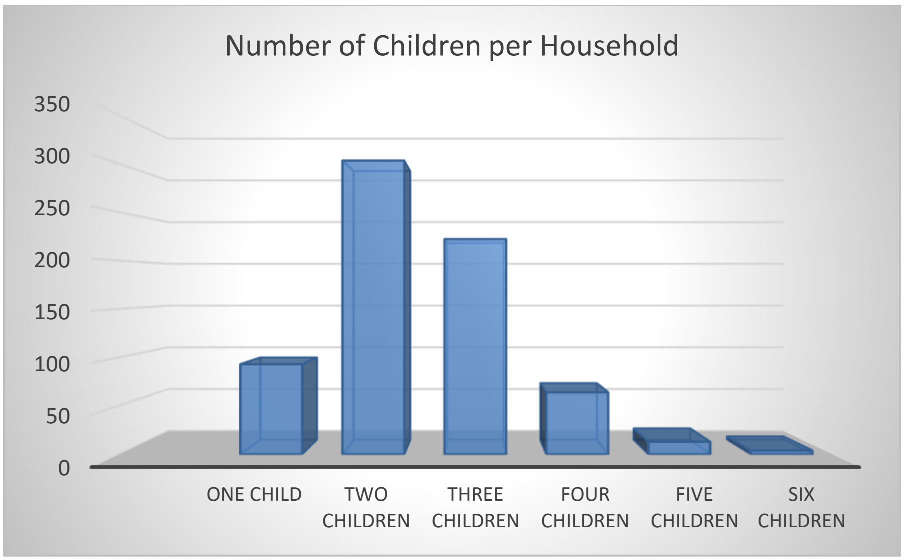
2. Please indicate your marital Status:



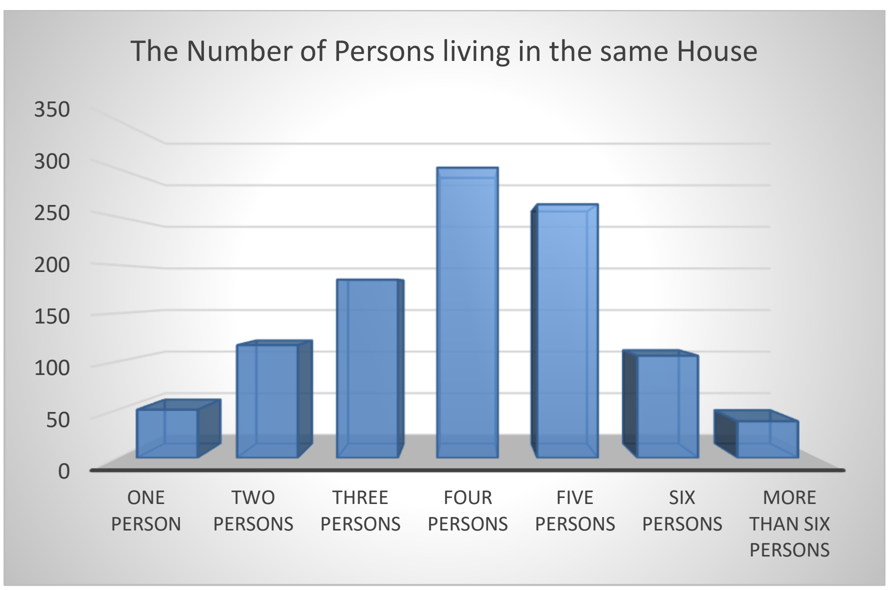
3. Do you have children?

Yes	701
No	112
Total	813

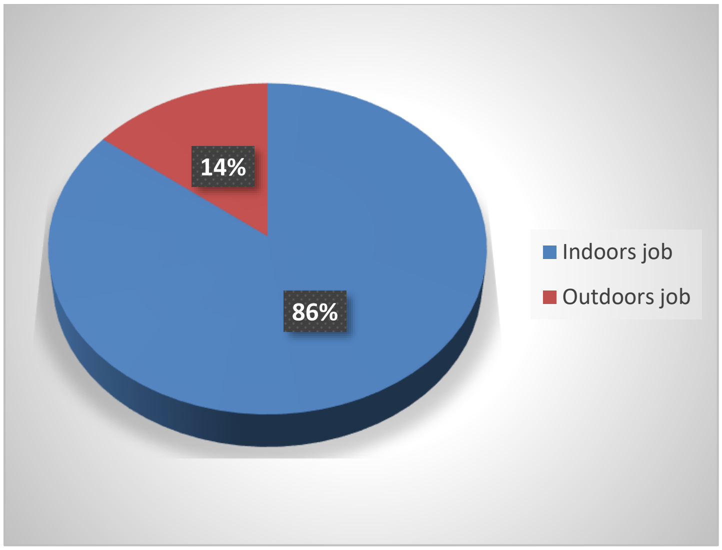
<u>Number of children per household</u>



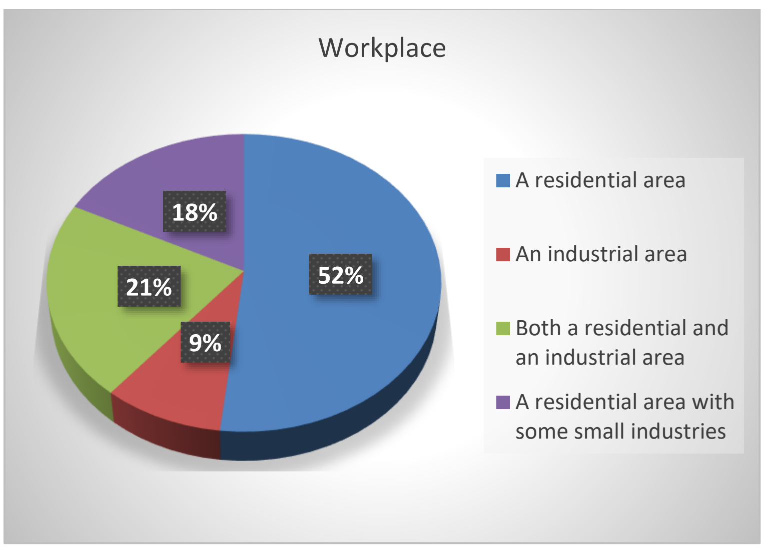
4. Please specify the number of members in your house:



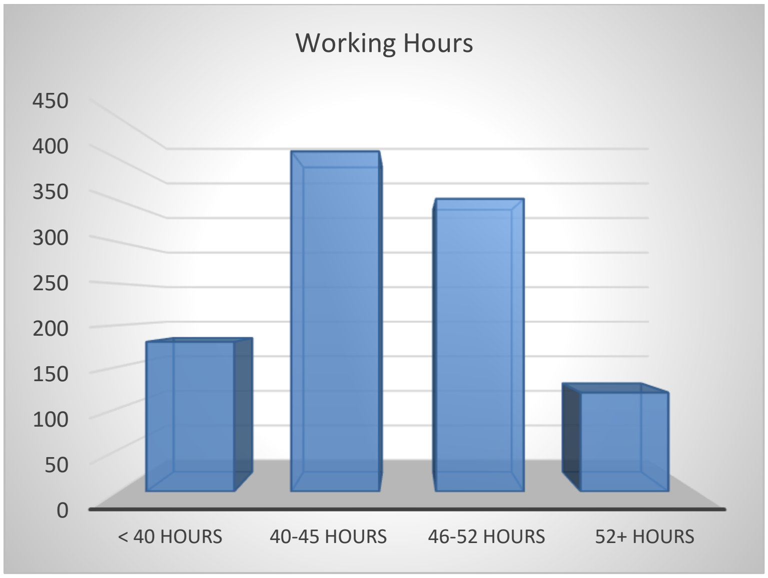
5. How do you describe your occupation?



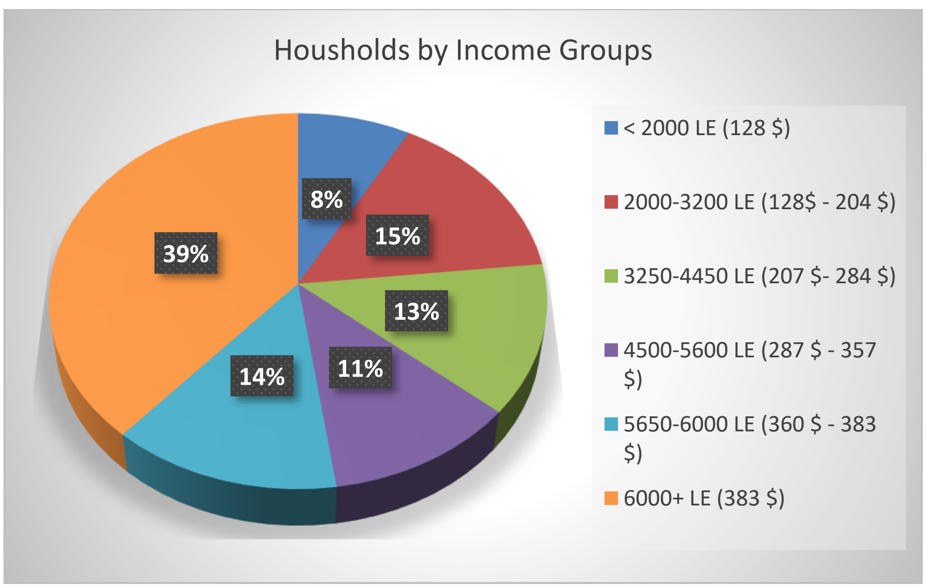
6. How do you describe your workplace?



7. Please state how many hours per week do you work:



8. How much is your monthly income?



3. Arabic Translation of the Survey Questions

يهدف هذا الإستبيان إلى تقديم المعلومات اللازمة لإجراء دراسة بحثية حول تقييم مخاطر تلوث الهواء على الصحة وحول تقديرالقيمة الاقتصادية لجودة الهواء في مصر.

تستغرق الإجابة على هذا الإستبيان حوالي ١٥ دقيقة.

برجاء قراءة المعلومات التالية بعناية قبل إتخاذ القرار بالمشاركة أو عدم المشاركة.

أهداف الدراسة: تهدف الدراسة إلى تقييم رغبة وإستعداد الأسرالمصرية لتحمل بعض النفقات من أجل تحسين جودة الهواء، وكذلك من أجل تقليل المخاطر الصحية المرتبطة بتلوث الهواء في كل من القاهرة الكبرى والإسكندرية.

دور المشارك: على المشارك في هذه الدراسة الإجابة على جميع الأسئلة الواردة في هذا الإستبيان المكون من خمسة أجزاء. يتضمن الجزئان الأول والثاني عدداً من الأسئلة تتعلق بكل من السمات السكانية والوعي البيئي لدى المشارك. أما في الجزء الثالث، فعلى المشارك أن يقرأ بعناية بعض المعلومات حول تلوث الهواء، ثم يجيب على الأسئلة التي تليها. يحتوي الجزء الرابع علي بعض الأسئلة بشأن العبء الاقتصادي لبعض الأمراض. أما الجزء الخامس والأخير فيتضمن أسئلة إضافية عن السمات السكانية للمشارك.

شروط المشاركة: يجب أن يكون المشارك (ذكراً أو أنثى) عائلاً لإحدى الأسر في القاهرة الكبرى أوالإسكندرية، كما يجب ألا يقل عمره عن ٢٤ عاماً.

حقوق المشارك: تضمن هذه الدراسة للمشاركين فيها حماية خصوصية المعلومات التي يقدمونها، حيث لن يطلب من المشاركين تقديم أية معلومات شخصية أو تعريفية (كالإسم أو العنوان مثلاً). كما أنه لا توجد لدى القائمين على الدراسة آلية يمكن بها التعرف على المشاركين من خلال إجاباتهم، وكذلك لا يمكن ربط البيانات المقدمة من المشارك بالموقع الجغرافي للحاسب الذي تم إجراء الإستبيان من خلاله. وفيما يخص البيانات المتضمنة في الإستبيان، فسيتم حفظها وتحليلها وقد تتم مشاركتها لأغراض بحثية.

طبيعة المشاركة: المشاركة في هذه الدراسة تطوعية، ويمكن للمشارك أن يقرر التوقف عن المشاركة في الإستبيان في أي وقت عن طريق إغلاق متصفح الإنترنت. وكذلك إذا قام المشارك بعدم الإجابة على أي أسئلة لا يرغب في الإجابة عليها فستعد تلك أيضاً مشاركة لاغية، حيث أنه لن يتم تحليل أي استبيان غير مكتمل.

إذا كان لديك أية أسئلة أو استفسارات، برجاء التواصل مع الباحث على البريد الإلكتروني: s.ghanem@uea.ac.uk

نشكرك على قراءة هذه المعلومات وعلى المشاركة في هذه الدراسة.

باختيارك المتابعة إلى الإستبيان، فإنك تؤكد على ما يلي:

- أنك قد قرأت وفهمت جميع المعلومات الخاصة بهذا المشروع البحثي.
- أنك تفهم جيداً أغراض الدراسة وما تتضمنه.
- أنك تدرك أن مشاركتك طوعية وأنك حر في الانسحاب في أي وقت دون إبداء الأسباب.
- أنك تدرك أن البيانات المتضمنة في الإستبيان سيتم حفظها وتحليلها، وقد تتم مشاركتها لأغراض بحثية.

الجزء الأول: السمات السكانية (١)

١ . العمر:

- ٢٤ ـ ٣٩ عاماً
- ٤٠ ـ ٥٩ عاماً
- ٦٠ عاماً فأكثر

٢. النوع:

- ذكر
- أنثى

٣ . محل الإقامة:

- القاهرة الكبرى
- الإسكندرية

الجزء الثاني: الوعي البيئي

1. **إرتفع مستوى ثاني أكسيد الكربون في الهواء بشكل ملحوظ خلال العقود الماضية كنتيجة لحرق الوقود الأحفوري (الفحم و الغاز ومشتقات البترول) . ما هو التأثير المباشر لزيادة تركيز ثاني أكسيد الكربون في الغلاف الجوي على الأرض؟**

- يصبح المناخ أكثر دفئاً
- يصبح المناخ أكثر برودة
- تنخفض مستويات الرطوبة في الجو
- تزداد مستويات الرطوبة في الجو
- لا أعلم
- سبب آخر (يرجى ذكر السبب ....)

2 . السبب الرئيسي لوفيات الأطفال على مستوى العالم هو:

- سوء التغذية
- حوادث السير
- تلوث المياه والهواء
- الحروب
- لا أعلم
- سبب آخر (يرجى ذكر السبب ....)

3. **أكمل العبارة التالية:**

" تستهلك حوالي 70% من المياه العذبة فى أغراض ...."

- الشرب
- الطهى
- الأنشطة الصناعية

- الري
- لا أعلم
- سبب آخر (يرجى ذكر السبب ....)

4. أي من الأشياء التالية لا يمكن إعادة تدويره وإستخدامه مرة أخرى؟

- الأكياس البلاستيكية
- الصحف الورقية
- إطارات السيارات
- الأوعية البلاستيكية
- لا أعلم
- لا شئ مما سبق

5. **السبب الرئيسي لظاهرة السحابة السوداء في القاهرة هو**:

- العوادم المنبعثة من وسائل المواصلات
- العوادم المنبعثة من محطات توليد الطاقة
- الحرق المكشوف للمخلفات الزراعية
- العوادم المنبعثة من المصانع
- سبب آخر (يرجى ذكر السبب ....)

6. ما هي الوسائل التي تستخدمها للحصول على معلومات بشأن كل من جودة الهواء، ومستويات إنبعاث العوادم، وتأثيرات التعرض لتلوث الهواء؟ يرجى اختيار كل ما ينطبق.

- صفحات المواقع الرسمية علي الإنترنت المرتبطة بوزارة البيئة أو بجهاز شئون البيئة.
- نشرات الأخبار الوطنية (من خلال التلفزيون أو الإذاعة)
- نشرات الأخبار الإقليمية أوالعالمية (من خلال التلفزيون أو الإذاعة)
- المواقع العامة على الإنترنت ومواقع التواصل الإجتماعي
- لست مهتماً بالحصول على معلومات بشأن جودة ونوعية الهواء
- أي شكل آخر من أشكال النشر (يرجى ذكر مصدر المعلومات.....)

<u>الجزء الثالث: تقييم المخاطر</u>

1. إلى أي مدى توافق أو تعترض على العبارة التالية:

"الآثار الصحية الناجمة عن تلوث المياه في مصر أكثر خطورة من الآثار الصحية لتلوث الهواء"

- أوافق بشدة
- أوافق
- أعترض
- أعترض بشدة
- لا أعلم

2. **أكمل العبارة التالية:**

قد أخشى الوفاة بسبب التعرض إلى خطر (..............) أكثر من الأخطار الأخرى.

- تلوث الغذاء
- تلوث الهواء
- تلوث المياه
- حوادث السير
- سبب آخر (يرجى ذكر السبب ....)

3. ما هو تقييمك لنوعية الهواء في منطقة إقامتك (على سبيل المثال: كلما إنخفضت كثافة الدخان أو الضباب كلما كانت نوعية الهواء أفضل):

- جيدة جدًا
- جيدة
- سيئة
- سيئة جدًا
- لا أعلم

4 . **ما هو تقييمك لنوعية الهواء في منطقة عملك (على سبيل المثال: كلما إزدادت كثافة الدخان أو الضباب كلما كانت نوعية الهواء أسوأ):**

- جيدة جدًا
- جيدة
- سيئة
- سيئة جدًا
- لا أعلم

<u>الجزء الرابع</u>

<u>السيناريو الأول : الإستعداد للإنفاق في سبيل تخفيض تلوث الهواء الناجم عن الجسيمات العالقة بنسبة ٥٠%:</u>

<u>المجموعة الأولى:</u>

يعد تلوث الهواء من أخطر المشكلات البيئية في مصر، حيث تشير قياسات جودة الهواء في مصر إلى وجود مستويات خطيرة من ملوثات الهواء، مثل الرصاص، أول أكسيد الكربون، ثاني أكسيد النيتروجين، ثاني أكسيد الكبريت، الأوزون، وكذلك المواد الجسيمية العالقة، خاصة الجسيمات العالقة الدقيقة التي يقل حجمها عن ٢,٥ ميكرومتر (ويشار إليها بالإختصار م.ج. ٢,٥). ويعد إرتفاع تركز الجسيمات العالقة الدقيقة في الهواء المشكلة الأكثر خطورة في مصر، حيث أن المتوسط السنوي لتركيز م.ج. ٢,٥ في مصر أعلى بنحو سبع مرات من المستوى المسموح به وفقاً لتوصيات منظمة الصحة العالمية.

ويساهم انتشار الأنشطة الصناعية في المناطق الحضرية، لا سيما في المناطق المكتظة بالسكان، بشكل كبير في زيادة التعرض للتركيزات المرتفعة من م.ج. ٢,٥ في الهواء، مما يشكل خطراً مستمراً على الصحة العامة للسكان. وتعمل الحكومة المصرية على خفض مستويات إنبعاث العوادم الصادرة عن الأنشطة الصناعية في المناطق الحضرية إلى مستوى يتوافق مع معايير منظمة الصحة العالمية، وذلك من خلال تطوير مناطق صناعية متخصصة. ومن المتوقع أن يؤدي نقل تلك الصناعات الملوثة إلى مناطق نائية إلى الحد بشكل كبير من تلوث الهواء بالجسيمات الدقيقة في المناطق الحضرية، مما سوف يؤدي إلى إنخفاض تلوث الهواء الناجم عن م.ج. ٢,٥ بنسبة تبلغ حوالي ٥٠ ٪.

1. **قد يؤدي نقل الصناعات الملوثة للهواء إلى مناطق نائية إلى زيادة أسعار بعض السلع التي تستهلكها، وهذا من شأنه أن يزيد من تكاليف المعيشة الخاصة بك.**

فإذا ترتب على تنفيذ هذا المشروع إرتفاع تكاليف معيشتك الشهرية، فهل تؤيد تنفيذه؟

- نعم
- لا

2. **إذا كانت الإجابة لا: يرجى توضيح سبب عدم رغبتك في دعم هذا المشروع الخاص بمكافحة التلوث:**

- لأن مسؤولية الحد من التلوث تقع على عاتق الحكومة
- لأن المتسببين في التلوث هم من يجب أن يتحملوا تكلفة ذلك المشروع
- لأنني لا أستطيع تحمل الإرتفاع في تكاليف المعيشة بسبب محدودية الدخل
- لأنني لا أعتقد أن المشروع سوف يقلل من تلوث الهواء بالفعل
- سبب آخر (يرجى ذكر السبب ....)

2. إذا كانت الإجابة بنعم: مع الأخذ في الإعتبار مستوى دخلك والنفقات الشهرية لأسرتك، إذا كانت التكلفة الإضافية التى سوف تتحملها أسرتك هي (٣٠٠،٢٠٠،١٠٠) جنيه شهرياً، فهل تؤيد نقل تلك المصانع من أجل تقليل تعرضك أنت وأسرتك لتلوث الهواء بالجسيمات العالقة بنسبة ٥٠٪؟

3. إذا كانت الإجابة بنعم: إذا ارتفعت أسعار السلع أكثر من المتوقع كنتيجة لتنفيذ هذا المشروع، بحيث أن التكلفة الإضافية التي سوف تتحملها أسرتك قد أصبحت الآن (٢٠٠ ، ٣٠٠ ، ٤٠٠) جنيه شهرياً، فهل ستستمر في دعم تنفيذ هذا المشروع؟ يرجى ملاحظة أنك إذا قبلت ذلك، فسوف تفقد جزءاً من دخلك -علي هيئة زيادة في المدفوعات- كان من الممكن أن تنفقه على أشياء أخرى ذات تكلفة مماثلة.

3. إذا كانت الإجابة بلا: إذا ارتفعت أسعار السلع بأقل من المتوقع نتيجة لتنفيذ هذا المشروع، والآن ستكون التكلفة الإضافية التى سوف تتحملها أسرتك هي (٥٠، ١٠٠، ٢٠٠) جنيه شهرياً، فهل ستدعم تنفيذ هذا المشروع؟ يرجى ملاحظة أنك إذا قبلت ذلك، فسوف تفقد جزءاً من دخلك -علي هيئة زيادة في المدفوعات- كان من الممكن أن تنفقه على أشياء أخرى ذات تكلفة مماثلة.

4. بالأخذ في الإعتبارمستوى دخلك والنفقات الشهرية لأسرتك، ما هو أقصى حد للزيادة في نفقاتك الشهرية يمكن أن تتقبله كي تدعم تنفيذ هذا المشروع؟

<u>المجموعة الثانية:</u>

يعد تلوث الهواء من بين أشد الأخطار التي تسهم في حدوث الوفاة المبكرة والعجز في جميع أنحاء العالم. وتؤكد بيانات منظمة الصحة العالمية على أن تلوث الهواء الخارجي (في الأماكن المفتوحة) في عام ٢٠١٧، كان مسؤولاً عن حوالي ثلث الوفيات الناجمة عن كل من سرطان الرئة وأمراض الجهاز التنفسي الأخرى، وكذلك الوفيات الناتجة عن أمراض القلب والأوعية الدموية. وتشير تلك البيانات أيضاً إلى أن تلوث الهواء بالمواد الجسيمية العالقة يرتبط إرتباطاً وثيقاً بالآثار الصحية الأكثر خطورة، وخاصة الجسيمات العالقة الدقيقة التي يقل حجمها عن ٢,٥ ميكرومتر (ويشار إليها بالإختصار م.ج. ٢,٥) ، حيث تشير الدراسات إلى أنه في مقابل كل زيادة بمقدار ١٠ ميكروجرام لكل متر مكعب في تركيز م.ج. ٢,٥ في الهواء، فإنه يحدث إرتفاع في إجمالي عدد الوفيات بنسبة ٤٪، كما تزداد الوفيات بسبب كل من أمراض القلب والرئة بنسبة ٦٪، والوفيات بسبب سرطان الرئة بنسبة ٨٪، والوفيات بسبب أمراض الجهاز التنفسي بنسبة ٠,٥٨٪، بالإضافة إلى إرتفاع معدل التردد على المستشفيات بنسبة ٨٪. وتؤكد الدراسات أيضًا، على الصلة الوثيقة بين تلوث الهواء ومخاطر الإصابة بسرطان المثانة وسرطان الكبد.

يبلغ المتوسط السنوي لتركيز م.ج. ٢,٥ في مصر مستوىً أعلى بنحو سبع مرات من المستوى المسموح به وفقاً لتوصيات منظمة الصحة العالمية. وتحتل مصر المرتبة الأولى على مستوى العالم فيما يتعلق بانتشار سرطان المثانة (يتسبب في ٨ حالات وفاة لكل مئة ألف فرد سنوياً)، كما تحتل المرتبة الرابعة فيما يتعلق بانتشار سرطان الكبد (يتسبب في ٢٧ حالة وفاة لكل مئة ألف فرد سنوياً). ويعد سرطان الرئة في مصر من أكثر أنواع السرطانات شيوعاً، حيث يمثل نسبة تقع بين ٥٪ إلي ٧٪ من جميع أنواع السرطانات. كما تعد مصر من بين الدول العشر الأولى من حيث الوفيات الناجمة عن أمراض القلب التاجية (تتسبب في ٢٠١٧ حالة وفاة لكل مئة ألف فرد سنوياً).

ويساهم انتشار الأنشطة الصناعية في المناطق الحضرية، لا سيما في المناطق المكتظة بالسكان، بشكل كبير في زيادة التعرض للتركيزات المرتفعة من م.ج. ٢,٥ في الهواء، مما يشكل خطراً مستمراً على الصحة العامة للسكان. وتعمل الحكومة المصرية على خفض مستويات إنبعاث العوادم الصادرة عن الأنشطة الصناعية في المناطق الحضرية إلى مستوى يتوافق مع معايير منظمة الصحة العالمية، وذلك من خلال تطوير مناطق صناعية متخصصة. ومن المتوقع أن يؤدي نقل تلك الصناعات الملوثة إلى مناطق نائية إلى الحد بشكل كبير من تلوث الهواء بالجسيمات الدقيقة في المناطق الحضرية، مما سوف يؤدي إلى إنخفاض تلوث الهواء الناجم عن م.ج. ٢,٥ بنسبة تبلغ حوالي ٥٠ ٪.

1. **قد يؤدي نقل الصناعات الملوثة للهواء إلى مناطق نائية إلى زيادة أسعار بعض السلع التي تستهلكها، وهذا من شأنه أن يزيد من تكاليف المعيشة الخاصة بك.**

فإذا ترتب على تنفيذ هذا المشروع إرتفاع تكاليف معيشتك الشهرية، فهل تؤيد تنفيذه؟

- نعم
- لا

2. **إذا كانت الإجابة لا: يرجى توضيح سبب عدم رغبتك في دعم هذا المشروع الخاص بمكافحة التلوث:**

- لأن مسؤولية الحد من التلوث تقع على عاتق الحكومة
- لأن المتسببين في التلوث هم من يجب أن يتحملوا تكلفة ذلك المشروع
- لأنني لا أستطيع تحمل الإرتفاع في تكاليف المعيشة بسبب محدودية الدخل
- لأنني لا أعتقد أن المشروع سوف يقلل من تلوث الهواء بالفعل
- سبب آخر (يرجى ذكر السبب ....)

2. إذا كانت الإجابة بنعم: مع الأخذ في الإعتبار مستوى دخلك والنفقات الشهرية لأسرتك، إذا كانت التكلفة الإضافية التى سوف تتحملها أسرتك هي (١٠٠،٢٠٠،٣٠٠) جنيه شهرياً، فهل تؤيد نقل تلك المصانع من أجل تقليل تعرضك أنت وأسرتك لتلوث الهواء بالجسيمات العالقة بنسبة ٥٠٪؟

3. إذا كانت الإجابة بنعم: إذا ارتفعت أسعار السلع أكثر من المتوقع كنتيجة لتنفيذ هذا المشروع، بحيث أن التكلفة الإضافية التي سوف تتحملها أسرتك قد أصبحت الآن (٢٠٠ ، ٣٠٠ ، ٤٠٠) جنيه شهرياً، فهل ستستمر في دعم تنفيذ هذا المشروع؟ يرجى ملاحظة أنك إذا قبلت ذلك، فسوف تفقد جزءاً من دخلك -علي هيئة زيادة في المدفوعات- كان من الممكن أن تنفقه على أشياء أخرى ذات تكلفة مماثلة.

3. إذا كانت الإجابة بلا: إذا ارتفعت أسعار السلع بأقل من المتوقع نتيجة لتنفيذ هذا المشروع، والآن ستكون التكلفة الإضافية التى سوف تتحملها أسرتك هي (٥٠، ١٠٠، ٢٠٠) جنيه شهرياً، فهل ستدعم تنفيذ هذا المشروع؟ يرجى ملاحظة أنك إذا قبلت ذلك، فسوف تفقد جزءاً من دخلك -علي هيئة زيادة في المدفوعات- كان من الممكن أن تنفقه على أشياء أخرى ذات تكلفة مماثلة.

4. بالأخذ في الإعتبارمستوى دخلك والنفقات الشهرية لأسرتك، ما هو أقصى حد للزيادة في نفقاتك الشهرية يمكن أن تتقبله كي تدعم تنفيذ هذا المشروع؟

السيناريو الثاني : الاستعداد للإنفاق فى سبيل تقليل مخاطر الوفاة المبكرة الناشئة عن تلوث الهواء بالجسيمات العالقة:

المجموعتين الثالثة والرابعة:

يعد تلوث الهواء من بين أشد الأخطار التي تسهم في حدوث الوفاة المبكرة والعجز في جميع أنحاء العالم. وتؤكد بيانات منظمة الصحة العالمية على أن تلوث الهواء الخارجي (في الأماكن المفتوحة) في عام ٢٠١٧، كان مسؤولاً عن حوالي ثلث الوفيات الناجمة عن كل من سرطان الرئة وأمراض الجهاز التنفسي الأخرى، وكذلك الوفيات الناتجة عن أمراض القلب والأوعية الدموية. وتشير تلك البيانات أيضاً إلى أن تلوث الهواء بالمواد الجسيمية العالقة يرتبط إرتباطاً وثيقاً بالآثار الصحية الأكثر خطورة، وخاصة الجسيمات العالقة الدقيقة التي يقل حجمها عن ٢,٥ ميكرومتر (ويشار إليها بالإختصار م.ج. ٢,٥) ، حيث تشير الدراسات إلى أنه في مقابل كل زيادة بمقدار ١٠ ميكروجرام لكل متر مكعب في تركيز م.ج. ٢,٥ في الهواء، فإنه يحدث إرتفاع في إجمالي عدد الوفيات بنسبة ٤٪، كما تزداد الوفيات بسبب كل من أمراض القلب والرئة بنسبة ٦٪، والوفيات بسبب سرطان الرئة بنسبة ٨٪، والوفيات بسبب أمراض الجهاز التنفسي بنسبة ٠,٥٨٪، بالإضافة إلى إرتفاع معدل التردد على المستشفيات بنسبة ٨٪. وتؤكد الدراسات أيضًا، على الصلة الوثيقة بين تلوث الهواء ومخاطر الإصابة بسرطان المثانة وسرطان الكبد.

يبلغ المتوسط السنوي لتركيز م.ج. ٢,٥ في مصر مستوىً أعلى بنحو سبع مرات من المستوى المسموح به وفقاً لتوصيات منظمة الصحة العالمية. وتحتل مصر المرتبة الأولى على مستوى العالم فيما يتعلق بانتشار سرطان المثانة (يتسبب في ٨ حالات وفاة لكل مئة ألف فرد سنوياً)، كما تحتل المرتبة الرابعة فيما يتعلق بانتشار سرطان الكبد (يتسبب في ٢٧ حالة وفاة لكل مئة ألف فرد سنوياً). ويعد سرطان الرئة في مصر من أكثر أنواع السرطانات شيوعاً، حيث يمثل نسبة تقع بين ٥٪ إلي ٧٪ من جميع أنواع السرطانات. كما تعد مصر من بين الدول العشر الأولى من حيث الوفيات الناجمة عن أمراض القلب التاجية (تتسبب في ٢٠١٧ حالة وفاة لكل مئة ألف فرد سنوياً).

ويعد النشاط الصناعي أحد المصادر الرئيسية لتلوث الهواء بالجسيمات العالقة الدقيقة (م.ج. ٢,٥). وفي سبيل الحد من ظاهرة تلوث الهواء، فإنه يمكن للحكومة أن تلزم المصانع بتركيب معدات إضافية للتحكم وتقليل مستوى إنبعاث العوادم الضارة، مما يؤدي إلى إنخفاض المخاطر الصحية الناجمة عن تلوث الهواء، ومن المقدر أن تركيب معدات التحكم في التلوث في المصانع سوف يقلل من مخاطر الوفاة بسبب تلوث الهواء بالجسيمات العالقة من ١١٩٢ حالة وفاة لكل مئة ألف شخص سنويا ، إلى (١١٤٢ ، ١٠٩٢) حالة وفاة لكل مئة ألف شخص سنويا.

1. سوف يؤدي إلزام المصانع بتركيب معدات إضافية لتقليل مستوى إنبعاث العوادم الملوثة للهواء إلى زيادة أسعار العديد من السلع التي تستهلكها، وهذا من شأنه أن يزيد من تكاليف المعيشة الخاصة بك.

فإذا إرتفعت نفقاتك المعيشية الشهرية بسبب هذا الإجراء، فهل ترغب في أن تقوم الحكومة بتنفيذه؟

- نعم
- لا

2. إذا كانت الإجابة بلا: يرجى توضيح سبب عدم رغبتك في دعم هذا الإجراء المكافح للتلوث:

- لأن مسؤولية الحد من التلوث تقع على عاتق الحكومة
- لأن المتسببين في التلوث هم من يجب أن يتحملوا تكلفة ذلك المشروع
- لأنني لا أستطيع تحمل الإرتفاع في تكاليف المعيشة بسبب محدودية الدخل
- لأنني لا أعتقد أن المشروع سوف يقلل من تلوث الهواء بالفعل
- سبب آخر (يرجى ذكر السبب ....)

2. إذا كانت الإجابة بنعم: مع الأخذ في الإعتبار مستوى دخلك والنفقات الشهرية لأسرتك، إذا كانت التكلفة الإضافية التى سوف تتحملها أسرتك هي (١٠٠،٢٠٠،٣٠٠) جنيه شهرياً، فهل تؤيد إلزام المصانع بتركيب معدات مكافحة التلوث لتقليل إحتمال وفاتك أو أي شخص من أسرتك كنتيجة للتعرض إلى تلوث الهواء بالجسيمات العالقة؟

3. إذا كانت الإجابة بنعم: إذا إرتفعت أسعار السلع أكثر من المتوقع كنتيجة لتطبيق هذا الإجراء، بحيث أن التكلفة الإضافية التي سوف تتحملها أسرتك الآن قد أصبحت (٢٠٠ ، ٣٠٠ ، ٤٠٠) جنيه شهرياً، فهل ستستمر في دعم تنفيذ هذا الإجراء؟ يرجى ملاحظة أنك إذا قبلت ذلك ، فسوف تفقد جزءاً من دخلك -علي هيئة زيادة في المدفوعات - كان من الممكن أن تنفقه على أشياء أخرى ذات تكلفة مماثلة.

3. إذا كانت الإجابة بلا: إذا ارتفعت أسعار السلع بأقل من المتوقع كنتيجة لتنفيذ هذا الإجراء، والآن ستكون التكلفة الإضافية التى سوف تتحملها أسرتك هي (٥٠، ١٠٠، ٢٠٠) جنيه شهرياً، فهل ستدعم تنفيذ هذا الإجراء؟ يرجى ملاحظة أنك إذا قبلت ذلك ، فسوف تفقد جزءاً من دخلك -علي هيئة زيادة في المدفوعات- كان من الممكن أن تنفقه على أشياء أخرى ذات تكلفة مماثلة.

4. بالأخذ في الإعتبارمستوى دخلك والنفقات الشهرية لأسرتك، ما هو الحد الأقصى للزيادة في نفقاتك الشهرية الذي يمكن أن تتقبله لكي تدعم تنفيذ هذا الإجراء؟ (.....) جنيه شهرياً

<u>الجزء الخامس: العبء الصحي والاقتصادي لتلوث الهواء</u>

1 . **هل تعاني أنت أو أي من أفراد أسرتك من أي من الأمراض التالية؟**

(يرجى تحديد عدد المصابين ، إن وجد)

- أمراض الجهاز التنفسي (مثل الربو، أمراض الانسداد الرئوي المزمن) (نعم / عدد المصابين ...) (لا)
- أمراض القلب والأوعية الدموية (مثل الذبحة الصدرية ، احتشاء عضلة القلب) (نعم / عدد المصابين ...) (لا)
- أمراض الأوعية الدموية الدماغية (مثل السكتة الدماغية) (نعم / عدد المصابين ...) (لا)
- سرطان الرئة (نعم / عدد المصابين ...) (لا)
- أمراض الكبد (نعم / عدد المصابين ...) (لا)
- سرطان المثانة (نعم / عدد المصابين ...) (لا)
- أمراض الكلى (نعم / عدد المصابين ...) (لا)

2. **تقريباً، ما هوعدد أيام تغيبك عن العمل شهرياً بسبب مرضك أو مرض أحد أفراد أسرتك:**

- لا يوجد
- يوم واحد
- يومان
- ثلاثة أيام
- أربعة أيام
- خمسة أيام
- أكثر من خمسة أيام

3 . **كم تبلغ النفقات الصحية التي تنفقها على علاج هذه الأمراض شهرياً؟**

- لا يوجد
- ١٠٠ جنيه أو أقل
- ١٠١ - ٥٠٠ جنيه

- ٥٠١ - ١٠٠٠ جنيه
- ١٠٠١ - ٢٠٠٠ جنيه
- ٢٠٠١ - ٤٠٠٠ جنيه
- ٤٠٠١ -٧٠٠٠ جنيه
- ٧٠٠١ - ١٠٠٠٠ جنيه
- ١٠٠٠١ جنيه أو أكثر

4 . من الذي يتكفل بدفع النفقات الصحية وتكاليف العلاج الخاصة بك وبأسرتك؟

- يتحمل التأمين الصحي (العام، أو الخاص، أو النقابي) جميع النفقات الصحية وتكلفة العلاج.
- يتحمل التأمين الصحي (العام، أو الخاص، أو النقابي) جزءاً من النفقات الصحية وتكلفة العلاج (من فضلك حدد نسبة التغطية التأمينية ....).
- ليس لدي تأمين صحي وأنا من يتحمل جميع النفقات الصحية وتكلفة العلاج.

5 . **هل لديك جهاز لتنقية الهواء في منزلك؟**

- نعم
- لا

6 . **إذا كانت الإجابة بنعم، كم تبلغ تكلفة إستخدام جهاز تنقية الهواء شهرياً تقريباً (إستهلاك الكهرباء والصيانة) ؟**

<u>الجزء السادس: السمات السكانية (٢)</u>

1 . **أعلى مستوى تعليمي حصلت عليه هو:**

- الشهادة الابتدائية
- الشهادة الإعدادية
- الشهادة الثانوية (عامة، أزهرية، فنية)
- شهادة الدبلوم الفني
- شهادة جامعية
- دراسات عليا (شهادة مهنية معتمدة، دبلوم عالي، ماجستير، دكتوراه)

2 . **حالتك الإجتماعية:**

- أعزب/ عزباء
- متزوج/ متزوجة
- مطلق/ مطلقة
- أرمل/ أرملة

3 . هل لديك أولاد؟ (نعم / ما عددهم ....) (لا)

4 . **ما عدد أفراد الأسرة المقيمين معك بالمنزل (.... ...)**

5 . **طبيعة وظيفتك:**

- وظيفة في مكان مغلق (مثلاً: مكتب، مصنع، عيادة)

- وظيفة في مكان مفتوح (مثلاً: موقع بناء- حقل)

6 . **يقع محل عملك في:**

- منطقة سكنية
- منطقة صناعية
- منطقة سكنية وصناعية
- منطقة سكنية بها بعض الصناعات الصغيرة

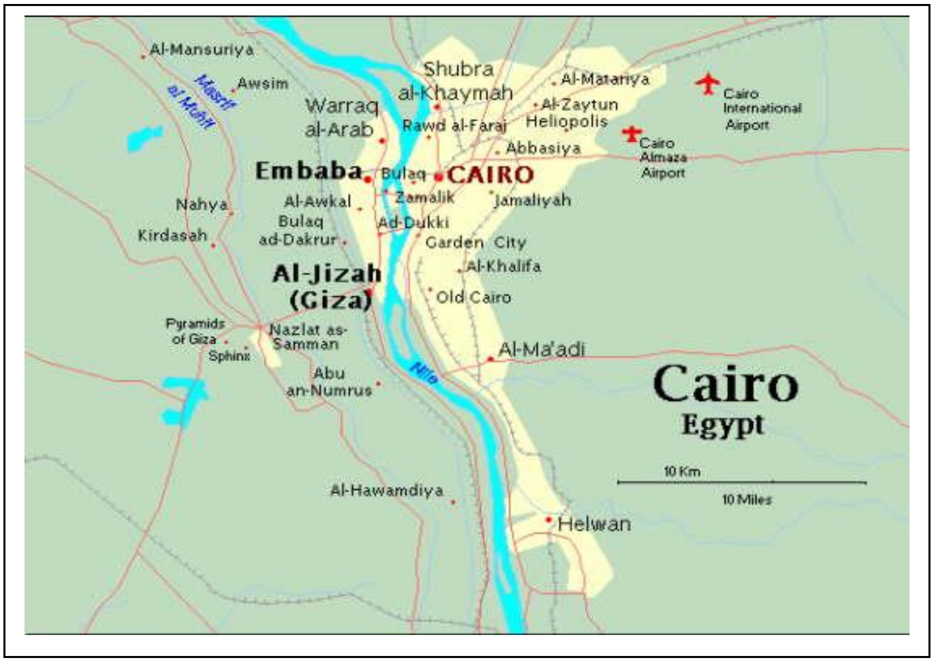
7 . **تقريباً، كم تبلغ عدد ساعات عملك الأسبوعية؟**

- أقل من ٤٠ ساعة
- من ٤٠ إلي ٤٥ ساعة
- من ٤٦ إلي ٥٢ ساعة
- أكثر من ٥٢ ساعة

8. **تقريباً، كم يبلغ دخلك الشهري؟**

- ٢٠٠٠ جنيه أو أقل
- ٢٠٠١ - ٣٢٠٠ جنيه
- ٣٢٠١ - ٤٥٠٠ جنيه
- ٤٥٠١ - ٥٦٠٠ جنيه
- ٥٦٠١ - ٦٠٠٠ جنيه
- ٦٠٠١ جنيه أو أكثر

Map of Greater Cairo Metropolitan Area



Map of Alexandria Governorate

Concluding Remarks

The main goal of sustainable development is to improve the standards of living, reduce poverty, and enhance the quality of life through improving population's health, wellness, and level of education, while simultaneously ensuring environmental sustainability or maintaining the natural capital necessary for the wellness and development of future generations. Environmental sciences focus on environmental sustainability, while research in medical and social fields focuses on improving the quality of life, and development economics focuses on alleviating poverty. A necessary step towards making progress in sustainable development is the integration of research and perspectives from all these fields in order to identify the trade-offs between the aspects of sustainability, as public policy-making processes often tend to be made upon the basis of these trade-offs and uses them in the formulation of critical decisions.

Therefore, providing policymakers with better information on such trade-offs between the dimensions of sustainable development can help in addressing the challenges and in prioritizing the interventions that would generate greater social gains. However, information regarding cause-effect relationships between the aspects of sustainable development is still lacking, because the interrelationships between them are not entirely explored and understood. This lack of information means that current development policies are being formulated and implemented without a full understanding of their impacts, especially in the long term. For example, in the short term there is usually a trade-off between protecting the environment and economic growth, also, there may be some health risks associated with different economic development strategies and plans. Policy interventions which are formulated based on better information of these trade-offs can help reduce some of the short-term trade-offs along with possible unintended consequences of such decisions and actions in the long term.

As a multidimensional complex phenomenon, sustainable development involves a set of relationships which explain the behaviour of many variables, where each of these variables indicates an aspect of sustainability. Thus, in order to explain the whole phenomenon, a simultaneous analysis of the three empirical relationships between environment-economic growth, health-economic activity, and environment-health is necessary and informative for decision makers.

This work focuses on exploring the way environmental degradation impacts long-term economic growth, emphasizing the link between environmental degradation and health as the main channel of transmission. This was done by simultaneously analyzing three empirical relationships: the first is the relationship between air pollution, in terms of $PM_{2.5}$ and economic growth, the second is the relationship between poor health, in terms of NCDs and economic performance, and the third is the relationship between air pollution and health.

Air pollution ranks among the top risk factors for death and disability worldwide, and therefore is a prominent example of environmental degradation. The WHO emphasized that approximately 91% of the world's population is exposed to air pollutant concentrations exceeding the recommended levels. In addition, ambient air pollution is the second leading cause of mortality and morbidity due to NCDs worldwide. Reducing the number of people suffering from NCDs has recently been added to the SDGs in the UN 2030 Agenda for Sustainable Development (Target 3.4). The WHO data reveals that NCDs kill more than 40 million persons every year, thus accounting for nearly 70% of all global deaths. Among these deaths, about 38% afflict people aged 30-69, and 80% occur in lower-middle and low-income countries.

Therefore, increases in NCDs pose substantial economic risks, as the costs of treating NCDs are enormous, both at the macro- and microeconomic levels. In addition, although NCDs represent a continuous fiscal burden for all countries, they have particularly significant economic implications in the least developed and developing ones, where NCDs mostly affect people in their productive age, when they are at the peak of their working lives, and are supporting their families, in contrary to the case in developed countries.

Our review of empirical literature on the relationship between the environment and economic growth shows that just a few studies have paid attention to the impact of $PM_{2.5}$ air pollution on economic performance via the health channel, and that none of these have employed the more wholesome simultaneous approach in their analysis of that tangled problem. In addition, although the global economic burden of NCDs attributable to $PM_{2.5}$ air pollution has gained attention in the past few years, there exists only a few empirical studies about it, and almost none of these empirical works on health and economic growth have emphasized mortality and morbidity due to NCDs attributable to ambient $PM_{2.5}$ air pollution as an indicator of the poor health linked to air pollution. The highest levels of air pollution are experienced in developing countries, which consequently bear the heaviest toll of diseases attributed to it, where more than 90% of air pollution related diseases occur in low- and middle-income countries. Despite this, very limited research has been conducted on the economic and health burdens of $PM_{2.5}$ air pollution in developing countries in general, and in middle eastern countries in particular.

In this study we address some of these drawbacks in the literature. First by employing a more suitable analytical approach which relies on a simultaneous system of equations, thus enables the identification of both the direct effect of environmental degradation on economic performance, and its indirect impact via the health channel, and second by focusing on mortality and morbidity due to NCDs attributable to ambient $PM_{2.5}$ air pollution, which is a more appropriate indicator for measuring the health burden of air pollution. Finally, we conduct a specific case study of Egypt as an example of a developing country.

The Egyptian economy shares some common characteristics with other developing economies, such as the low per capita income, the high population growth rate, the dependence on primary sectors, the weak environmental protection and health care sectors, the high levels of air pollution, and the heavy burden of air pollution on public health. Therefore, Egypt represents a suitable case study for a number of reasons: the first is that Egypt's economic development strategies and industrialization orientation, combined with weak environmental management and lack of environmental policies, especially those focusing on reducing emissions, have resulted in a widespread and severe air pollution. The second reason is that Egypt is the top country worldwide with respect to the health burden attributable to ambient $PM_{2.5}$ air pollution, and despite this, very limited research has been conducted on the economic burden of NCDs, and both the economic and health burdens of $PM_{2.5}$ air pollution, neither from the macro- nor the micro-economic perspectives. The third reason is that almost 50% of the Egyptian labour force are outdoors workers and therefore are more vulnerable to the adverse health effects of air pollution. Finally, Egypt has limited natural resources, and it mainly relies on its human resources as the main factor of production, thus achieving sustainable economic development in Egypt greatly depends on the quality of human capital in terms of health, education, and skills.

Therefore, we started our empirical investigation by exploring both the direct impact of ambient $PM_{2.5}$ air pollution, as an example of environmental degradation, and its indirect impact via the health channel, in terms of mortality and morbidity due to NCDs attributable to ambient $PM_{2.5}$ air pollution, on economic growth, for a panel of 145 developed and developing countries, during the period from 1990 to 2015. We have explicitly formulated a system of three equations for the determinants of economic growth, health, and air quality, where each of them reflects one aspect of sustainability. The entire system is estimated simultaneously using a 3SLS panel estimation approach. The superiority of full information approaches when estimating a system of equations is well known, especially for large samples, because these approaches take into consideration the endogeneity problem of regressors (using all the remaining exogenous variables of the system as instruments), and they consider the interconnections among the three equations through the cross-equation error correlations.

Our simultaneous analysis indicates that the link between poor health attributable to environmental degradation and long-term economic growth is stronger than what is generally recognized. We found that holding all other variables constant, an increase by one per cent in the concentration of $PM_{2.5}$ is estimated to cause a direct decline in the growth of per capita income by four percentage points, and to slow down the economic growth indirectly through increasing mortality and morbidity attributable to NCDs, as measured through DALYs due to ambient $PM_{2.5}$ air pollution, by about eight percentage points. At the same time, a reduction by one per cent in exposure to $PM_{2.5}$ can result in decreasing DALYs due to ambient air pollution by nearly five percentage points.

The burden of NCDs due to environmental degradation, especially in low-income regions, stands as a stark barrier to economic growth and therefore it must be addressed carefully, and integrated into mainstream development strategies and planning. The higher elasticity of economic growth with respect to both air pollution and poor health attributable to air pollution in developing countries, compared to the developed ones, can be taken as evidence of the significant indirect effect of controlling air pollution on the growth of per capita income in these countries, and that higher economic gains can be achieved through controlling air pollution which leads to consequent improvements in health conditions. Furthermore, the economy in developing countries mostly relies on sectors in which workers are regularly exposed to ambient conditions, such as the agriculture, mining, and construction sectors, therefore these countries may adjust their way towards economic growth and speed up their economic performance through investment in environmental improvements.

Our findings also confirm that efforts to reduce air pollution through policy intervention, such as the activation of environmental laws and legislations, and switching from reliance on polluting fuels that cause series environmental harm to cleaner energy sources, can result in great reductions of air pollution in developing countries, which have higher levels of pollution compared with developed nations, because the concentration levels of air pollution are more elastic in developing countries, and thus the human capital and economic returns of these procedures may be larger. Our findings also suggest that environmental regulation can contribute to health improvements, and thus it can be considered as some kind of investment in human capital and hence in economic growth.

In general, our findings shed light on the role that health can play as an engine to drive economic growth, and on the way that air pollution affects this role, which is a critical step in informing air quality interventions, and in establishing and implementing effective air pollution control policies, especially in developing countries where the decision making process is confronted with the challenge of protecting the environment and mitigating environmental hazards while enhancing economic growth.

In our second empirical study, we explore the driving forces of environmental degradation in Egypt and the way they affect the country's chances for sustaining development. In this chapter we have introduced an analysis of the Egyptian economy during the period 1950-2010, with a special focus on the way population growth, as one of the major driving forces of environmental degradation, hinders sustainable development in Egypt, 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, which consequently lowers labour productivity.

The results of the second study indicate that an increase in population was associated with a significant increase in air pollution. Also, economic growth and energy use have been found to be associated with a monotonic upward trend in emissions. Air pollution has been one of the major causes of increasing morbidity and mortality due to cardiovascular and respiratory diseases over the last few decades in Egypt. Handling the health problems caused by air pollution is one of the most important obstacles facing Egypt in its endeavors towards sustainable development. The ability of the Egyptian health and environmental management sectors to effectively deal with various direct and indirect health impacts of air pollution is limited by their inefficiency and disorganization, and the scarcity of resources allotted to them. In accordance with evidence which shows the presence of causality links between air pollution and poor health outcomes, and between poor health and labour productivity, it can be said that the policies and procedures implemented in order to reduce air pollution can be also considered to be an investment in human capital in Egypt, and therefore they also serve as tools for enhancing economic growth.

In addition, the findings indicate that a significant part of the low productivity of the Egyptian labour force can be explained by poor health of the population, and that affluence did not play a significant role in reducing the incidence of environment related diseases in Egypt during the study period. Also, educational level was found to have a slightly negative association with poor 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 ambient air pollution cannot be avoided easily.

Moreover, like many other countries throughout the world, Egypt has been very slow to develop health and environmental policies and strategies. This can partly be traced back to the gaps in knowledge and perceptions of the problems raised by pollution, and the insufficient evidence to act upon. Much work is required in order to achieve a successful reduction of the health threats arising from poor environmental conditions, where the lack of information on the health risks resulting from environmental deterioration does severely hinder efforts to control this problem. The Egyptian health and environmental sectors have to play an essential advocacy role in highlighting the links between health, environment, and economic growth in the context of sustainable development, and in planning future policies and actions.

The results also emphasize that the ineffectiveness of environmental protection policies and deficiencies in their implementation during the study period in Egypt has played a significant role in increasing harmful emissions, and hence air pollution and environmental degradation in general. It is important to underline that effective environmental policies require careful calculations of all costs and benefits that may be acquired through pollution reduction, and therefore a cost-benefit analysis for policy interventions could be extremely informative in this regard.

Estimating the economic value of improving air quality and the health benefits associated with it are key inputs into the estimation of the benefits and costs of air pollution mitigation strategies and policies, which may enhance individuals' probability of survival. Therefore, our third empirical study aimed at estimating the economic value of improved air quality (or the implicit shadow price of air quality) and the value of mortality risk reduction in Egypt. An essential motive for that work is that research on the economic value of air quality and the health risks associated with air pollution in Egypt is still at a very early stage. To the best of our knowledge, the economic value of air quality and the value of the reduction in mortality risk attributed to ambient $PM_{2.5}$ air pollution resulting from industrial activities have never been evaluated for Egypt using CVM before. We used a CV survey instrument in order to estimate the WTP for improved air quality and for reducing the mortality risk associated with air pollution, along with the corresponding VSL, in both the Greater Cairo and Alexandria metropolitan areas, where more than 80 percent of the country's industrial activities take place. An Internet-based survey was conducted in Arabic, and administered through the online survey research software Qualtrics, for 1060 households which have been apportioned using the quota sampling technique.

Qualitative analysis of the survey responses shows that a large portion of Egyptian households are suffering from pollution related diseases, and that they also seem to have a low level of environmental awareness. Nevertheless, nearly 70% out of the 1051 households surveyed were positive towards supporting efforts to improve air quality at both study sites. This indicates that although Egypt is among the lower-middle income countries and that it doesn't have a specific budget allocated for improving air quality, a high percentage of Egyptian households are willing to pay for reducing the air pollution load. The results also show that the main reason for households for not supporting pollution control projects is their belief that the government, along with the polluters, are responsible for controlling pollution. Low income is also a significant reason for unwilling to support pollution control projects, especially for respondents who are females, residents of Greater Cairo, or among the younger ages. Our results also indicate that air in Greater Cairo is perceived to be more polluted and to be causing greater health concerns compared with Alexandria. This is reflected in the higher estimated figures of both the WTP for improved air quality and the VSL in Greater Cairo, compared with their counterparts in Alexandria.

Our results suggest that the mean WTP estimate for reducing $PM_{2.5}$ air pollution resulting from industrial activities ranges between 212 LE and 302 LE per month (13.5US$ and 19.3US$). In quantifying the benefits of policies aiming at saving lives through mortality risk reduction, our results suggest that the WTP ranges between 203.8 LE and 293 LE per month (13.35US$ and 18.7US$) for a 5 in 10000 mortality risk reduction, and ranges between 219 LE and 317.6 LE per month (US$ 14 and 20.3US$), for a 10 in 10000 mortality risk reduction. Accordingly, the corresponding VSL estimates range between about 3.81 million LE to nearly 7.0 million LE. We have found that the information provided in the CV scenarios does affect the WTP values, as providing the respondents with additional information about the adverse health impacts of air pollution has significantly increased their willingness to support pollution control projects and their WTP values. Furthermore, the estimated WTP for improved air quality of the respondents who were well informed about the negative consequences of air pollution on their health was found to be higher than that of the respondents who were not provided with the same information.

The level of mortality risk reduction has been found to be a significant predictor of the respondents' WTP. Regarding risk perceptions, our results suggest that water pollution and traffic accidents are subjectively perceived by Egyptian households to be more serious sources of health risks than air pollution. The results indicate that, in general, the estimated WTP values are likely to be higher for those with higher incomes. Our study provides some evidence of a positive relationship between age and the VSL, as we have found that the WTP for mortality risk reduction is significantly lower among the older respondents. Regarding the impact of health status on the WTP, our result suggests that people with severe health conditions, such as cancer, are willing to pay less than other individuals for reductions in the risk of dying. We also found that people are willing to pay more for risk reduction if they are in a good health status.

A positive relationship between educational level and the WTP has not been found to be consistent across all levels of education. We found that certain segments of the sample were significantly more willing to pay for improved air quality and for mortality risk reduction compared to others, particularly females, those of younger age (24-39 years old), people living in the more polluted areas, those who have children, and those who are already applying some protective measures. Finally, the results of this study should encourage the implementation of effective policies for reducing industrial air pollution levels in urban settings in Egypt, which can possibly generate substantial health and economic gains. Also, spreading awareness of air pollution and the associated health risks to the overall population should play a key role in supporting environmental protection efforts.

In general, it can be said that achieving sustainable development in Egypt requires moving from a short-term view of the economy, where sacrifices in social and environmental conditions are seen as necessary for the achievement of the short-term economic gains, to a long-term view, where the both society and the environment are integrated in the main stream of the economic development plans, in other words there is a need to adapt a national development strategy where the maximum integration between economic, social and environmental policies is achieved. Also, changes in human behaviour and actions in relationship to the environment is a must. Understanding what motivates individual and group behaviour, may help in structure incentives to shift behaviour in desirable directions, and in designing policies and institutions to achieve desirable social outcomes. Our work represents a step in this direction.

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