ePDH online.com

Credit: 2 PDH

Course Title:

Renewable Energy, Emissions and Health

Approved for Credit in All 50 States

Visit epdhonline.com for state specific information including Ohio's required timing feature.

3 Easy Steps to Complete the Course:

1. Read the Course PDF
2. Purchase the Course Online & Take the Final Exam
3. Print Your Certificate

Chapter 8

Renewable Energy, Emissions, and Health

María del P. Pablo-Romero, Rocío Román, Antonio Sánchez-Braza and Rocío Yñiguez

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/61717

Abstract

The deployment of renewable energy sources is reviewed in this research showing the importance that they have reached in most countries. The International Energy Agency has insisted on the importance of their promotion all over the world, considering that at least one renewable energy source is available in all countries. The aim of this chapter is to show that although renewables are an effective alternative to the use of fossil fuels, there are other important positive externalities. As the fossil fuels are the main source of greenhouse emissions and other air pollutants, the negative effects that they have on human health, such as respiratory and cardiovascular diseases, have been recently shown in many studies. When renewables contribute to reducing the use of fossil fuels and associated air pollutant emissions, they have a positive effect on human health. Therefore, policy makers have to take into consideration all these positive externalities of renewable sources, when evaluating the possibility of their promotion. However, this evaluation should also take into consideration that not all renewable energy sources have equivalent positive effects. Our final conclusion is that governments should be supported by recent research when deciding the most appropriate energy mix for a country.

Keywords: Renewable energy, environmental health, air emissions, environmental policy

1. Introduction

Since 2006, when the Stern report was published [1], commissioned by the UK Treasury, new research has revealed the negative impacts that climate change may have on economic growth and health. The impacts of economic change are based on the assumption that greenhouse gases will raise the average temperature in the next 50 years by between 2°C and 3°C, which represents a threat to the basic elements of human life in different parts of world: access to water, food production, health, land use, and environment. Furthermore, as empirical evidence has shown, these harmful effects resulting from climate change will be accelerated to the extent that the world will warm more, with poor countries being mainly affected [2].

Weather conditions affect the patterns of diseases such as diarrhea, malaria, malnutrition, etc., most of which affect children and youth in low-income countries [3]. Some of these effects have already taken place [4, 5], not by generating new diseases, but rather by exacerbating existing illnesses, the effects concerning respiratory diseases being particularly important.

According to the Global Energy Assessment Report 2012 [6], the direct effects of climate change, which increase health issues, are manifested in the increase in heat waves and rising sea levels. Climate change favors the increase of heat waves and, these heat waves generate an increase in the number of deaths due to heart attacks, when temperatures rise above 30 degrees and certain level of humidity is reached. Also, higher temperatures increase the formation of ozone, which in turn has negative effects on respiratory and cardiovascular health. Furthermore, scientists expect that the sea level may rise by a meter or more this century [7, 8]. This increase in sea level will have negative effects on the health of the population and crops. Additionally, climate change will also affect health indirectly, through changes in nutrition and changes in the development of infectious diseases that often increase when temperatures are rising.

Within the field of combating climate change is set the target of reducing the use of polluting energy. Two policies are combined to obtain the reduction: energy efficiency and the substitution of polluting energy by alternative sources such as nonpolluting energy sources or renewable energies.

Renewable energy production has its basis in reducing emissions to the environment, either by reducing CO_2 emissions or other air pollutants such as $PM_{2.5}$ associated with transportation, which also have a direct negative effect on health.

At the global level, various policies are intended to replace polluting fuels with renewable energies in different percentages in the coming years. The ultimate goal of such substitution is also the reduction of emissions by certain percentages. For example, this is the case of the EU target for 2020, in which the need to reduce emissions by 20% is established, along with the target of 20% of renewable energy participation in energy consumption.

The development of these clean energy sources is encouraging the study of their effects on health, either by mitigating climate change or by improving air quality. In this regard, several studies have been developed to assess the impact on the health cost of implementing renewable energy. Previous analysis gives an overall perspective for Denmark [9] and gives a more specific analysis about the impact that the mitigation of certain particles has on health, that is, the impact of renewable energy on health by reducing $PM_{2.5}$ [10].

The novelty of our chapter is to highlight that one of the most important positive externalities of using renewable energies is that they contribute to reduce CO_2 and air emissions and improve human health.

The key question is that renewable energies are becoming a solution to the abatement of CO_2 in most developed countries as substitute fossil fuels that are pollutants, they contribute to reducing CO_2 and air pollutant emissions.

http://dx.doi.org/10.5772/61717

Additionally, the research studies link the effects of climate change, or more accurately, the effects of CO_2 emissions on health are becoming more frequent. Of course, the epidemiological studies are those that provide information about the effects that the air pollutants cause on human health.

The final aim of this chapter is to combine this information in order to improve the research studies on this important issue, the link among renewable energies, emissions, and health.

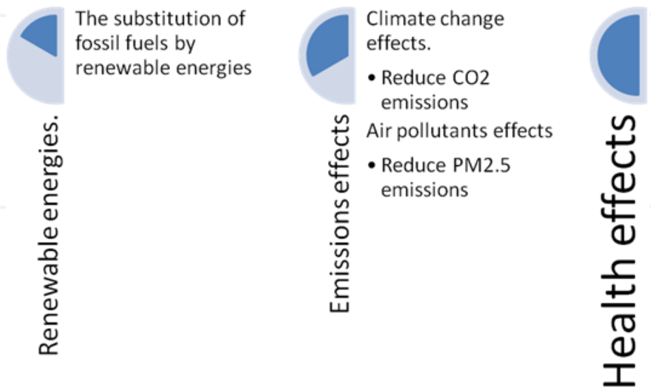

Figure 1. Renewable energies, emissions, and health.

This book chapter aims to establish a recent literature review on studies linking the establishment of renewable energy systems with their effect on health, distinguishing between the studies that are focused on the link between climate change and health with a global perspective, and those studies that link the effects of some specific pollutant on health.

Therefore, after an initial introduction about the health effects of climate change and environmental pollution, Section 2 is devoted to the current situation and development of renewable energy, and the main proposals for increased production of these energies replacing polluting energies. Section 3 gives a literature review of analysis linking renewable energy and impact on health. A discussion of energy policies in relation to the results of previous studies is made in Section 4. Finally, Section 5 summarizes the conclusions.

2. The development of renewable energy

2.1. CO_2 emissions intensity

REmap 2030, made by the International Renewable Energy Agency (IRENA), shows that under current policies and national plans (the "business as usual" case), average carbon dioxide (CO_2) emissions will only drop to 498 g/kWh by 2030. That is not enough to keep atmospheric CO_2 levels below 450 parts per million (ppm), and, what is more, severe climate change is expected to take place. A doubling in the share of renewable energies could help check climate change by reducing the global average emissions of CO_2 to 349 g/kWh, which is equivalent to a 40% intensity reduction compared to the 1990 levels (see Figure 2) [11, 12].

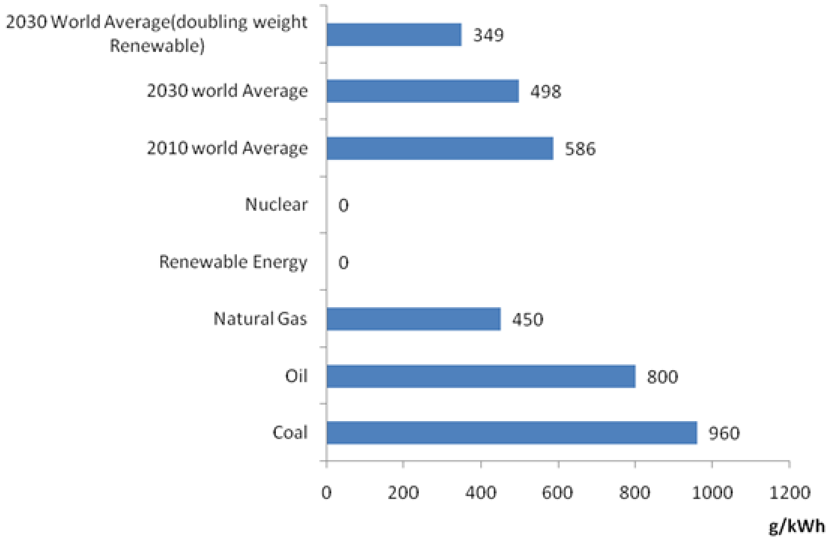

Figure 2. CO_2 emissions intensity

2.2. Renewable energy capacity

Each year since 2011 there has been, on a global basis, an addition of more than100 GW of new renewable energy capacity. This figure is the same as Brazil's total installed generation capacity, or double Saudi Arabia's. Renewables are more than 50% of the net capacity which has been added to the global power sector since 2011. This means that more new renewables capacity is being set up than that in fossil and nuclear power put together. This led to the share of renewables in total electricity production surpassing a record 22% by 2013; 16.4% of this was hydro and 3.6% was solar photovoltaics (PV) and wind. The renewable energy industry employed about 6.5 million people in 2013, an increase of 14% over 2012 [11].

We can see an increasing use of up-to-date renewable energy in four different markets: transport fuels, power generation, heating and cooling, and rural/off-grid energy services. When we break down modern renewables, taken as a share of total final energy use in 2012, we get the following: hydropower generated about 3.8%; other renewable power sources were 1.2%; heat energy was around 4.2%; and transport biofuels supplied more or less 0.8% [13]. According to REN21 [13], from 2009 to 2013, the installed capacity, as well as the output of most renewable energy technologies, increased at rapid rates, especially in the power sector (see Figure 3).

http://dx.doi.org/10.5772/61717

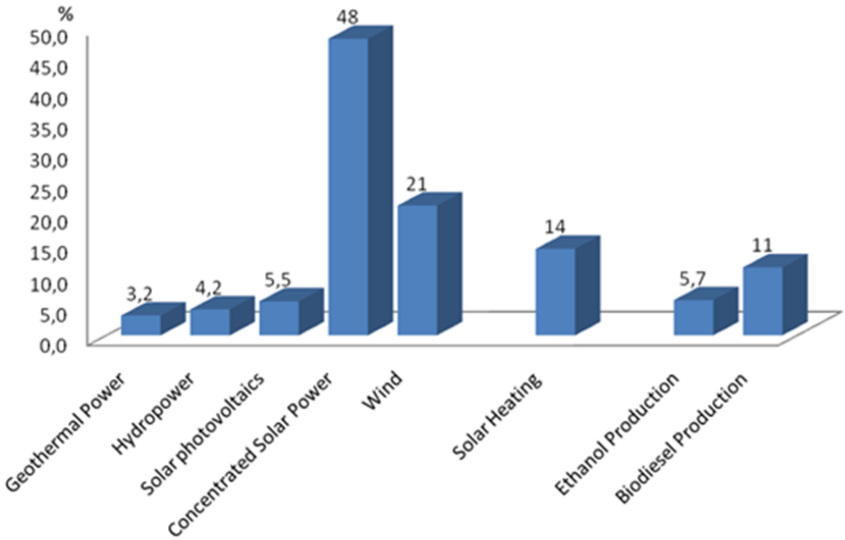

Figure 3. Average annual growth rates of renewable energy capacity and biofuels production, 2009–2013

However, a number of European countries that is on the increase have decreased, at times ex post facto, their financial backing for renewables in excess of the reduction of in technology costs. This has been brought on, partly, by the continuing economic crisis in certain and by increasing competition with fossil fuels. Doubts about policy have raised capital costs, hindering the financing of projects and lowering investment. During 2013, Europe continued to see a notable loss of start-up companies, especially solar PV (in the PV market, capacity additions dropped for a second year in a row, from 17GW in 2012 to 10GW in 2013).

Furthermore, renewables work in an uneven area where the prices of energy are not completely in line with external factors. Worldwide subsidies for fossil fuels and nuclear power remain high despite talk about phasing them out, thereby fostering energy use which is inefficient and at the same time also impeding investment in renewables. Estimates for the global cost of fossil fuel subsidies range from USD 544 billion to USD 1.9 trillion, figures which are notably above those for renewable energy [13].

2.3. Renewable energy by regions

In general, despite some exceptions in Europe and the United States, there were some significant and positive developments for renewables in 2013. Wind power advanced more steadily into Africa and Latin America; concentrating solar thermal power moved its focus further to the Middle East and to North and South Africa; renewable process heat fueled industries from Chile to Europe to India; and solar PV maintained its spread across the globe, with most capacity on-grid but also notable increases in off-grid markets in developing countries [13].

In the United States, the percentage of renewable generation increased to almost 12.9% (12.2% in 2012). This was in spite of a decrease in hydropower output and competition from cheap natural gas coming from shale. Meanwhile, between 2008 and 2013 the quantity of net coal-based electricity generation went down by nearly 19%.

China had not before had more new renewable power capacity than new fossil and nuclear capacity. Altogether, renewables were more than 20% (> 1,000 TWh) of its electricity generation. Seventy-two percent of new electric capacity was due to renewable power installations in the European Union. This is 70% more than in 2012. A decade before, in the EU-27 plus Norway and Switzerland the situation was completely different, with conventional fossil generation being approximately 80% of new capacity.

Spain was the first country to generate more electricity from wind power than from any other source, with 20.9% of the total.

There was an increase of over 4 GWin India's renewable capacity, up to approximately 70.5 GW. Though hydropower was most of the total (62%), solar PV and wind was close to 70% of 2013 renewable additions. All the same, India's power capacity is increasing fast, and renewables did not reach 17% of total additions from all sources in 2013.

Due to its competitiveness compared to the rest of the sources of energy generation, wind power was not allowed to be part of an auction in Brazil. The year ended with Brazil having 3.5 MW of wind power capacity, and there were contracts for another 10 GW. Although worldwide investment in solar PV decreased by almost 22% compared to 2012, new capacity installations went up by over 32%. By the beginning of 2013, 18 countries used non-hydro renewable resources to generate over 10% of their electricity, an increase – in 2010 only 8 countries did so. Austria, Kenya El Salvador, Lithuania, and Denmark were among these countries.

Looking at communities and regions from around the world, we see many that have targeted, or have already completed a successful transition to 100% renewable electricity. Some examples are Djibouti, Scotland, and the small-island state of Tuvalu. All of them plan to use renewable sources to get all their electricity by the end of the decade [13].

On a worldwide basis, homes and work places are choosing "green" instead of from both traditional utilities and new energy providers, freely opting to buy renewable energy whose production is not within regulatory requirements. Germany is still at the forefront in voluntary renewable power purchasing. Domestic customers increased from 0.8 million in 2006 to 4.9 million in 2012. This stands for 12.5% of the country's private households. In 2011, they bought 15 terawatt-hours (TWh) of green power, and in this year a further 10.3 TWh was purchased by commercial customers. Austria, Belgium (Flanders), Finland, Hungary, the Netherlands, Sweden, Switzerland, and the United Kingdom are among other major European green power markets, although the market share in these countries remains below the level of Germany. There are also green power markets in Australia, Canada, Japan, South Africa, and the United States [13].

http://dx.doi.org/10.5772/61717

Major industrial and commercial customers in Europe, India, Mexico, and the United States continued to turn to renewables to reduce their energy costs at the same time as increasing the reliability of their energy supply. Many set ambitious renewable energy targets in 2013, installed and operated their own renewable power systems, or signed purchase agreements to purchase directly from renewable energy project operators, by passing utilities.

In Australia, Japan, and Thailand, as well as in North America and several countries in Europe, the number of community-owned and co-operative projects also rose. Denmark has a long history of co-operatively owned projects. In 2013, close to 50% of the renewable power capacity in Germany belonged to its inhabitants and around 20 million Germans are living in regions that are considered as having 100% renewable energy [14].

Renewables have been helped by continuing advances in technologies, decreases in prices, and innovations in financing, driven largely by policy support. These developments mean that under many circumstances renewable energy is cheaper than new fossil and nuclear installations, and as a result of this, for a greater number of consumers in developed and developing countries it is more affordable. Furthermore, there is a growing awareness of renewable energy technologies and resources, and their capability to keep up with a demand for energy that is on the rise. At the same time, these renewables are creating jobs, accelerating economic development, reducing local air pollution, improving public health, and reducing carbon emissions [13].

There is also the issue of serious health problems which directly result from burning fossil fuels. The United States Environmental Protection Agency recently rated the cost of national ill health due to fossil fuel costs at between USD 362 billion and USD 887 billion per year. The European Union's Health and Environment Alliance noted that coal-fired power plant emissions cost as much as EUR 42.8 billion in health expenditure on an annual basis (IRENA) [11].

Meanwhile, pressure is on the rise for 1.3 billion people to begin accessing electricity. A great number of them live in areas which are hard to reach, thus excluding the usual large-scale power plants and transmission systems. At the same time, 2.6 billion people suffer from severe health problems due to having to use traditional biomass and cook with conventional stoves [11].

These tendencies mean that there is an obvious need for a change. Although fossil fuels drove the first industrial revolution, even in the new period of shale oil and gas, there is still the matter about their being compatible with sustainable human well-being. The time is ripe for a period of prevailing, sustainable, and cost-competitive modern renewable energy. Renewable energy technologies which supply electricity, heating and cooling, and transportation is at the moment used all over the world and trends lead us to consider that these technologies will globally continue to grow. In the recent past, renewables interested environmentally oriented people as an alternative to traditional fuels. Nowadays, it is seen that they are not only beneficial from the environmental point of view but also boost the economy, diversify the sources of revenue, and vitalize fresh advances in technology [13].

3. Renewable energy and health

3.1. Climate change and health

Climate scientists have observed that CO_2 concentrations in the atmosphere have been increasing significantly over the past century, the concentration of CO_2 in 2013 being about 40% higher than in the mid-1800s [15]. The Fifth Assessment Report from the Intergovernmental Panel on Climate Change states that human influence on the climate system is clear [16] as the rise of greenhouse gases (GHG) increase the global mean temperatures. In that sense, as stated in [17], most of the observed increase in global average temperature since the mid-twentieth century is very likely due to the observed increase in anthropogenic GHG concentrations.

The rise in temperatures has implications for life and human health. According to the World Health Organization [18], potential risks to health include deaths from thermal extremes and weather disasters, vector-borne diseases, a higher incidence of food-related and waterborne infections, photochemical air pollutants, and conflict over depleted natural resources. The valuation of these effects is complex because many effects on climate change depend on physical, ecological, and social factors. Therefore, according to the recent report by IPCC [16], all the various scientific studies that exist so far are debatable, since they are based on a number of assumptions, some of them very controversial. Also, many of these studies do not consider catastrophic changes or many other factors that can affect the economy of countries.

Despite these limitations, according to the World Health Organization [18], climate change was estimated to be already responsible for 0.2% of deaths in 2004, 85% of these being child deaths. Likewise, climate change was responsible for 3% of diarrhea, 3% of malaria, and 3.8% of dengue fever deaths worldwide. In addition, increased temperatures hastened as many as 12,000 additional deaths (not included in the above percentage because the years of life lost by these individuals were uncertain). Evenly, it will cause some 250,000 additional deaths annually between 2030 and 2050; 38,000 elderly people from exposure to heat; 48,000 from diarrhea; 60,000 from malaria; and 95,000 from child malnutrition.

Some studies have analyzed the impact of climate change on health in some countries in particular. Thus, in the study by [19] it is estimated that 166,000 deaths and about 5.5 million disability-adjusted life years (DALYs, a measure of overall disease burden) are due to cardiovascular disease, malnutrition, diarrhea, malaria, and floods.

The report titled Environmental Health Perspectives (EHP) [20] notes that the effects of climate change on health can be classified into 11 broad human health categories. Table 1 lists the main diseases associated with these categories.

Diseases	Effects of climate change on health
Asthma, respiratory allergies, and airway diseases	The global rise in asthma is indirectly related to climate change [21]. Climate change may increase the incidence and exacerbation of many respiratory allergic diseases. Some risk for respiratory disease can be clearly linked to climate change.

Diseases	Effects of climate change on health
Cancer	Climate change will result in higher ambient temperatures that may increase the transfer of volatile and semi-volatile compounds from water and wastewater into the atmosphere, changing subsequent human exposures [22]. Climate change is expected to increase heavy precipitation and flooding events, which may increase the chance of toxic contamination Depletion of stratospheric ozone, will result in increased ultraviolet (UV) radiation exposure, which increases the risk of skin cancers and cataracts [23].
Cardiovascular disease and stroke	There is evidence of climate sensitivity for several cardiovascular diseases, with both extreme cold and extreme heat directly affecting the incidence of hospital admissions for chest pain, acute coronary syndrome, stroke, and variations in cardiac dysrhythmias, though the reported magnitude of the exposure-outcome associations is variable [24-28]. There is also evidence that heat amplifies the adverse impacts of ozone and particulates on cardiovascular disease [29, 30]. Increased burden of $PM_{2.5}$ is associated with increased hospital admissions and mortality from cardiovascular disease, as well as ischemic heart disease [31, 32]. Indirectly, displacement related to disasters is frequently associated with interruptions of medical care for chronic medical conditions [33] Climate is also implicated in another indirect risk for cardiovascular disease: the incidence of certain vector borne and zoonotic diseases (VBZD) with cardiovascular manifestations [34].
Foodborne diseases and nutrition	Climate change may impact rates of foodborne illness through increased temperatures, which are associated with increased incidence of foodborne gastroenteritis Changes in ocean temperature and coastal water quality are expected to increase the geographic range of V. vulnificus and cholera [35]. Increased temperatures also affect rates of campylobacteriosis and salmonellosis. In [36] was stated a 2.5–6% relative increase in the risk of foodborne illness for every degree centigrade rise in temperature..
Heat-Related morbidity and mortality	The health outcomes of prolonged heat exposure include heat exhaustion, heat cramps, heat stroke, and death [37]. Prolonged exposure to heat may exacerbate pre-existing chronic conditions such as various respiratory, cerebral, and cardiovascular diseases [38]. The levels of pollen and other allergens are also higher in case of extreme heat.
Human developmental effects	Climate change will lead to changes in agricultural practices that might increase pesticide use. (e.g. DDT). Pesticides have been linked to decreases in fertility [39, 40] and to effects on fetal loss, child growth, and male reproductive development [41-43].

Diseases	Effects of climate change on health
Mental health and stress-related disorders	A variety of psychological impacts can be associated with extreme weather and other climate related events. Extreme weather events such as hurricanes, wildfires, and flooding, can lead to mental health disorders [44]. Prolonged heat and cold events can create chronic stress situations that may initiate or exacerbate mental disease and stress-related disorders
Neurological diseases and disorders	Effects of climate change on ocean health result in increased risks to neurological health from ingestion of or exposure to neurotoxins in seafood and fresh and marine waters, even a single low-level exposure to algal toxins [45]. Exposure to a number of agents whose environmental presence may increase with climate change may have effects on neurological development and functioning (pesticides, herbicides, heavy metals, extreme weather events etc.)
Vector borne and zoonotic diseases	Climate is one of several factors that influence the distribution of vector borne and zoonotic diseases (VBZD) such as Lyme disease, Hantavirus, West Nile virus, and malaria
Waterborne diseases	Climate change is expected to produce more frequent and severe extreme precipitation events worldwide and heavy rainfall is correlated with more than half of the outbreaks of waterborne diseases [46].
Weather-related morbidity and mortality	The health impacts of the extreme weather events include direct impacts such as death and mental health effects and indirect impacts such as population displacement and waterborne disease outbreaks
Compiled from the report by EHP [20]	

Table 1. Effects of climate change on health

Likewise, climate change will have the greatest effect on health in societies with scarce resources, little technology, and frail infrastructure. After reviewing what happened in the past, it has been shown in [47] throughout history, higher temperatures have reduced economic growth mainly in poor countries, not only reducing the level of production but also growth, and with a greater effect in agriculture, industrial, and political stability.

3.2. Renewable energy, emissions, and health

To avoid the adverse impacts of climate change, the Cancun Agreements of the Conference of Parties (COP) [48] called for limiting global average temperature rise to no more than 2°C above pre-industrial values, which means decreasing CO_2 by 50–85% below 2000 levels by 2050 [17]. Among the many human activities that produce greenhouse gases, the use of energy represents by far the largest source of emissions, with CO_2 resulting from the oxidation of carbon in fuels during combustion dominating the total GHG emissions [15].

It is necessary to evaluate every step of the entire system of the fuel cycle, from the extraction of raw materials to final consumption of energy, in order to make a quantitative estimate of

http://dx.doi.org/10.5772/61717

the risks to health from the various energy systems. According to [49], energy technologies can be classified into three groups, depending on the risks to health.

First, the fuels group: These technologies are characterized by the use of fossil fuels or biomass: coal, oil, natural gas, wood, and so on, the burning of which produces large amounts of air pollution and solid waste.

Second, the renewable group: This group is characterized by use of diffuse renewable resources with low energy density: sun, wind, water, the capturing of which requires large areas and construction of expensive facilities. Public risks are low, due to their low emissions, mostly confined to low-probability accidents, such as dam failures, equipment failures, and fires.

Third, the nuclear group: This includes nuclear fission technologies, characterized by high energy densities in the processed fuel, with corresponding low quantities of fuel to process and generating little waste to transform. Public risks are located in routine operations of reactors.

Thus, emissions given off by each technology are different and, therefore, their effect on climate change will also be distinct. In addition, technologies also differ in the way in which these emissions occur, as in some cases they are concentrated in the areas of production and in other cases in the territories of use.

Given the distinction between energy technologies, the Intergovernmental Panel on Climate Change [50] collects the lifecycle GHG emissions of each technology from estimates obtained in previous studies. According to the Intergovernmental Panel on Climate Change [50], without taking into account emissions related to land use change (LUC), the lifecycle GHG emissions normalized per unit of electrical output (g CO_2eq/kWh) from technologies powered by renewable resources are generally found to be considerably less than from those powered by fossil fuel-based resources. In that sense, renewable energy sources play a role in providing energy services in a sustainable manner and, in particular, in mitigating climate change.

The estimates of lifecycle GHG emissions for broad categories of electricity generation technologies calculated [50] show that all electricity generation technologies powered by non-renewable resources are much higher than those powered by renewable resources, except for nuclear (Figure 4). The median values for all renewable energy range from 4 to 46 g CO_2 eq/kWh, while these values range from 480 to 1,000 g CO_2 eq/kWh for non-RE (except nuclear). Among RE, photovoltaic and biopower technologies are those which emit more, up to 2–3 times above the maximum for other renewable energy technologies. Thus, the maximum value for lifecycle GHG emissions for petroleum gasoline and diesel is around 110 g CO_2 eq/MJ of fuel while the maximum value for biodiesel is 78 g CO_2 eq/MJ of fuel and for ethanol 70 g CO_2 eq/MJ of fuel. Nevertheless, not all biofuel systems are equally efficient in reducing GHG emissions compared to their petroleum counterparts. For example, ethanol from Brazilian sugarcane (45 g CO_2 eq/MJ of fuel) has lower GHG emissions than that produced from wheat and corn (70 g CO_2 eq/MJ of fuel).

Given the differences in emissions of different technologies, the potential impacts on human health due to emissions from the complete life cycle of future power generation, by using the

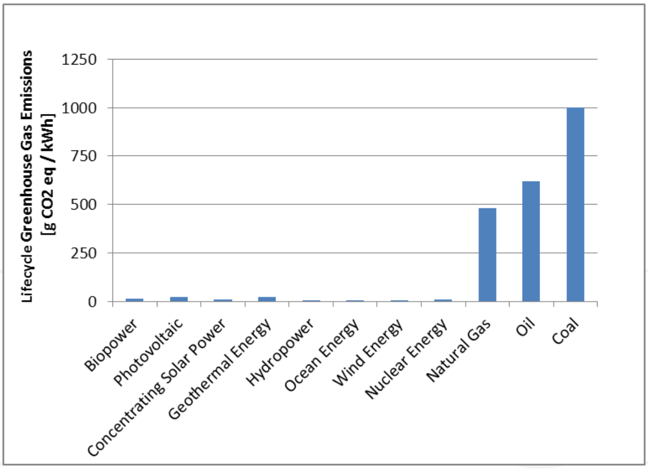

Figure 4. Estimates of lifecycle GHG emissions for electricity generation technologies (medium values)

Life Cycle Assessment (LCA) method, has been calculated [51]. LCA is a standardized method used to quantify environmental burdens and the potential impacts on human health and the environment, due to the production and consumption of goods and services. It allows for an evaluation of the environmental performance of fossil, nuclear, and renewable power generation technologies. Health effects related to climate change, and considered in the study, include malnutrition, diarrhea, cardiovascular diseases, coastal and inland flooding, and malaria.

The results of the LCA show that total human health impacts have a similar pattern as GHG emissions according to the hierarchic and individualist perspectives: fossil electricity generation has the highest levels of GHG emissions-human health impacts, while nuclear and renewables technologies have impacts of a scope somewhat lower, and fossil fuels with carbon capture and storage show intermediate levels. Nevertheless, when considering the egalitarian perspective, which regards the broadest range of potential health damages, and contemplates the longest time horizon, health impacts from natural gas power generation are in the same range as nuclear and some renewables [51].

3.3. Renewable energy, air pollutants, and health

In addition to reducing GHG emissions, renewable energy technologies can also offer benefits with respect to air pollution and health, compared to fossil fuels. According to the World Health Organization [52], the air pollutants that are emitted by energy technologies which have the most important impacts on human health are particulate matter (PM), nitrous oxides (NOx), sulfur dioxide (SO_2), and non-methane volatile organic compounds (NMVOC).

The IPCC highlights that non-combustion renewable energy technologies and nuclear power cause comparatively minor emissions of air pollutants [50]. The higher cumulative lifecycle emissions of NOx, SO_2, and $PM_{2.5}$ per unit of electricity generated are provoked by the

http://dx.doi.org/10.5772/61717

combustion of hard coal, lignite, oil, and biomass in steam turbines. The higher emissions of NMVOC are provoked by the combustion of natural gas and oil in steam turbines. The SO_2 emissions from the combustion of lignite in steam turbines is around 27 g/kWh, while from the steam turbine combustion of oil and hard coal it is 14 g/kWh and 8 g/kWh, respectively. Meanwhile the highest emissions of SO_2 from renewable energies are for biomass, at around 3 g/kWh. This pattern is quite similar for $PM_{2.5}$. The NOx emissions from wood steam are around 6 g/kWh, from oil steam turbines 4.5 g/kWh, and from hard coal steam turbines 4 g/kWh. Alternatively, the maximum NMVOC emissions are registered for the natural gas steam turbines (0.7 g/kWh) and oil-fired steam turbines (0.55 g/kWh). The biogas cogeneration and roof-top PV are the renewable technologies which emit more NMVOC, with 0.25 and 0.2 g/kWh, respectively.

There are also observed differences when considering the use of different transport fuels. The use of gaseous fuels tends to reduce air pollution compared to liquid fuels [53]. The use of ethanol and biodiesel blends tends to reduce carbon monoxide (CO) and hydrocarbon emissions, compared to gasoline and diesel. Nevertheless, NOx emissions seem to be higher. Alternatively, future electric or fuel cell vehicles offer a substantial potential for reductions in air pollution if electricity or hydrogen from renewable energy sources is used as the energy carrier [54, 55].

The health effects of ambient air pollution result from a complex mixture of combustion products. Nevertheless, negative effects have been most closely correlated with three: fine PM, SO_2, and tropospheric ozone [56, 57]. Additionally, the main health impacts of these pollutants are associated with emissions by fossil fuel and biomass combustion [56, 58], the first related to transport activities. Table 2 shows the health outcomes associated with transport-related air pollutants according to the WHO report Promoting Health While Mitigating Climate Change [59].

Associated transport-related pollutants	Health outcome
Black smoke, ozone, $PM_{2.5}$	Mortality
Black smoke, ozone, nitrogen dioxide, VOCs, CAPs, diesel exhaust	Respiratory disease (non-allergic)
Ozone, nitrogen dioxide, PM, VOCs, CAPs, diesel exhaust	Respiratory disease (allergic)
Black smoke, CAPs	Cardiovascular diseases
Nitrogen dioxide, diesel exhaust	Cancer
Diesel exhaust; also equivocal evidence for nitrogen dioxide, carbon monoxide, sulfur dioxide, total suspended particles	Adverse reproductive outcomes

Source: [59]

Table 2. Health Outcomes Associated with Transport-Related Air Pollutants

It is also important to consider patterns of household fuel use, especially for developing countries. The Global Energy Assessment estimates that in 2005 about 2.8 billion people, mostly in the poorest countries, relied on solid fuels such as biomass, charcoal, and coal for cooking and other household energy needs [6]. Anyway, although both household poverty and rural location predict the use of solid fuels [60], these are still used wherever available, even in many high-income countries, as a heating fuel [61].

Poor households often used solid fuels in inefficient, poorly vented combustion devices, which results in significant waste of fuel energy and emission of toxic products of incomplete combustion. Besides, this unfit use leads to exposures that are significantly detrimental to the health of family members, particularly to women and children, who spend the most time in or near the kitchen. Very young children are especially at risk because they are highly exposed during vulnerable developmental periods [6].

The amounts and relative proportions of the various pollutants generated by solid fuel combustion depend on a number of factors, including fuel type and moisture content, stove technology, and operator behavior. Notwithstanding carbon monoxide and particles being the most commonly measured pollutants, a range of other products of incomplete combustion is found in solid fuel smoke, including phenols, oxides of nitrogen, quinones/semiquinones, chlorinated acids such as methylene chloride, and dioxins [62, 63]. Table 3 shows some of these pollutants from the combustion of biomass and fossil fuels, and their known toxicological characteristics.

Pollutant	**Known toxicological characteristics**
Particulates (PM_{10} , $PM_{2.5}$)	Bronchial irritation, increased inflammation reactivity, reduced mucociliary clearance, reduced macrophage response
Carbon monoxide	Reduced oxygen delivery to tissues due to formation of carboxyhemoglobin
Nitrogen dioxide (relatively small amounts from low temperature combustion)	Bronchial reactivity, increased susceptibility to bacterial and viral lung infections
Sulfur dioxide (relatively small amount from most biomass)	Bronchial reactivity (other toxic end points common to particulate fractions)
Organic air pollutants: Formaldehyde 1,3 butadiene Benzene Acetaldehyde Phenols Pyrene, Benzopyrene Benzo(a)pyrene Dibenzopyrenes Dibenzocarbazoles Cresols	Carcinogenicity Co-carcinogenicity Mucus coagulation, cilia toxicity Increased allergic sensitization Increased airway reactivity
Source: [64, 6, 63]	

Table 3. Toxic pollutants from the combustion of biomass and fossil fuels.

http://dx.doi.org/10.5772/61717

The deployment of renewable energy should yield increased health benefits, and opportunities for policy measures combining climate change and (urban) air pollution mitigation are increasingly recognized.

Studies of the environmental benefits of clean energy initiatives tend to either focus on specific emission reduction objectives or on analyzing the overall emission reductions of multiple pollutants, including GHG and criteria pollutants [65].

A Texas Emissions Reduction Plan analysis in 2004 assessed the potential for clean energy to help meet NOx air quality requirements as part of a State Implementation Plan. Thus, the Texas Commission on Environmental Quality evaluated this plan and calculated that it achieved an annual reduction of NOx emissions of 346 tons in 2004 through energy efficiency and renewable energy. NOx reductions over the period 2007 to 2012 were projected to range from 824 tons per year in 2007 to 1,416 tons per year in 2012, which represent 0.5% and 1% of Texas NOx emissions in 2005, respectively [66, 67].

In the same vein, a Wisconsin study in 2007 measured CO_2, SO_2, and NOx emission reductions from the state's Focus on Energy Program, an energy efficiency and renewable energy project. This study found annual emission displacements of 1,365,755 tons of CO_2, 2,350 tons of SO_2, and 1,436 tons of NOx from 2001 through 2007, which respectively represent about 2%, 1%, and 2.5% of Wisconsin emissions in 2005 [67, 68].

Alternately, some studies have reassessed the economic cost of overcoming the recommended levels of air pollutants. The study performed in [69] quantifies the health cost of road-traffic related air pollution in Austria, France, and Switzerland. This study is based on the average yearly population exposure to particulate matter with an aerodynamic diameter of less than 10 μm (PM_{10}). Across the three countries (74 million inhabitants), the health costs due to traffic-related air pollution for the year 1996 amount to some 27 billion €, which represents approximately 1.7% of GDP. More recently, the study in reference [70] analyzes the economic costs associated with the hospitalization of children in the city of Seville, due to respiratory diseases caused by exposure to PM2.5 levels above the recommended limits. Moreover, a review of studies that have been conducted about this issue can be found in [71]. These authors provide a critical and systematic review of the societal costs of air pollution-related ill health studies. They find a total of 17 studies, mostly related to PM_{10} particles.

So, it can be understood that the decrease in emissions, that can be achieved through the use of less pollutant renewables, is going to be associated with less diseases and therefore with a lower economic cost. However, fewer studies have quantified the health benefits of clean energy initiatives. Methods to translate emission reductions into changes in air quality and associated health benefits can be complicated. Recently, some studies have been carried out to evaluate how renewable energy can reduce the negative effects of air pollutants [65].

The study in [72] compares the health impact of populations exposed to fine particles ($PM_{2.5}$) during their whole lifetime with two energy scenarios: the baseline (BL) scenario and the low carbon, maximum renewable power (LC-MRP) scenario. The results show that, compared to the BL scenario in which the emission factors are frozen at the 2005 level, the LC-MRP scenario, with the implementation of the current legislation on air pollution, results in a 58% reduction of $PM_{2.5}$ concentrations in Europe, reducing the loss of life expectancy by 21%. Likewise, the study concludes that a reduction of $PM_{2.5}$ concentrations by 85% and a reduction of health impact by 34% could be achieved if all technically feasible emission reduction measures were applied.

In [73], it analyzes the cost savings by the year 2050 that can be achieved when a 100% renewable energy systems is designed compared to the current systems in the case of Denmark, in which the primary energy supply has been kept constant for 35 years. The health costs are estimated on the basis of six different emissions: SO_2, NOx, CO_2, particulates ($PM_{2.5}$), mercury, and lead and are related to enumerated lost working days, hospital admissions, health damage, and deaths. The results show that while the combined health costs for the reference energy systems for 2015, 2030, and 2050 are approximately 14–15 billion DKK/year, the savings in the health costs are approximately 2 billion DKK in 2015, approximately 7 billion DKK in 2030, and approximately 10 billion DKK in 2050 when the energy system is 100% renewable.

Likewise, in [74], the authors use a simple damage function methodology to quantify some of the health co-benefits of replacing coal-fired generation with wind or small hydro in China. The authors estimate the health co-benefits of an average wind or hydro project in terms of number of hospital stays for respiratory or cardio-pulmonary conditions per year avoided due to the reductions in emissions of SO_2, NOx, and particulates.

4. Discussion

The relatively recent deployment of RE all over the world is justified in the need for substitution of fossil fuels. The first aim is to delay and reduce the future consequences of climate change provoked by GHG emissions.

Although claims for the effects of climate change have been criticized and even disputed, most countries have opted for a RE strategy path. The International Energy Agency (IEA) has devoted the Renewables Information report to highlighting the importance of RE sources, providing a comprehensive review of historical and current market trends in OECD countries, including preliminary data for 2013. As the IEA stated, the role of RE is expected to increase significantly over time in all scenarios considered with greater contributions to the power generation, heating and cooling, and transport sectors [12].

The advantages of using RE sources are still being quantified, but overall they allow countries to reduce the fossil fuels dependency, because it is considered that all countries enjoy at least one renewable resource and most of them have more than one available. Also, the benefits of using RE sources include the deployment of new technologies linked to RE sources, opening new job opportunities, and seem to be more feasible for coping with the energy demand. These actions are conducted by the so-called Green Economy.

Additionally, the RE sources contribute to reducing the GHG emissions and other air pollutants as soon as they substitute the use of fossil fuels. All these benefits of RE sources have

http://dx.doi.org/10.5772/61717

been used to justify the Governments' promotion of RE sources. As soon as RE sources deploy positive externalities, they should be promoted.

In fact, the main difficulty is to know to what extend they should be promoted by Governments. To answer this question, many efforts have been made in order to quantify these positive effects. Additionally, they have been transformed into monetary terms with the aim of providing further information. Then, the answer will be, the RE sources should be promoted as much as the benefits that they generate.

The feed-in system has been the most usual energy policy for RE sources promotion. An attempt to evaluate the positive externalities of using RE sources in the Spanish electricity market was done by [75]. The final aim of this research was the following. Firstly, in the paper is evaluated what would happen in Spanish electricity market if pollutant energy sources were substituted by promoted RES, in terms of CO_2 avoided. Secondly, the avoided CO_2 emissions generated by RES are compared with the funds they received from the Spanish feed-in system. Third, authors calculate the economic balance of promoted RES. In 2011, approximately 10% of premiums paid to promote RES for electricity could be explained by the monetary value of CO_2 emissions avoided by not using alternative pollutant energy sources, such as coal and combined cycle.

The feed-in system has been the most usual energy policy for RE sources promotion. An attempt to evaluate the positive externalities of using RE sources in the Spanish electricity market was done by [75]. The final aim of this research was the following. Firstly, the supported RES for electricity is evaluated in terms of CO_2 emissions avoided when they are introduced in the Spanish electricity market instead of other potential polluting energy sources. Secondly, these positive environmental externalities of supported RES for electricity were compared with the funds they received from the Spanish feed-in system, in order to estimate the economic balance of this support system. The results for 2011 show that approximately 10% of premiums paid to promote RES for electricity could be explained, from an economic point of view, by the monetary value of CO_2 emissions avoided by not using alternative energy sources, such as coal and combined cycle.

However, the most recent research about the deployment of RE sources is focused not only on the benefits from the climate change point of view, but also on the positive effects on human health. The reason is that it is not only GHG emissions that have effects on human health, but also other air pollutants such as ozone precursors and particulate matter are quite dangerous.

Great efforts have been made by some countries in order to meet not only the GHG international commitments but also to follow WHO recommendations in the air quality guide [52]. However, there are still important differences among countries about the percentage of population that are affected by upper limits of air pollutants as recommended by WHO [52].

While many efforts have been made in relation to the GHG emissions and the number of countries willing to reach an agreement is becoming more numerous, there is an important lack of international commitments when considering other pollutants.

There are areas such as the European Union, where, in addition to the climate change policy, there is an air pollution policy that covers the limits of pollutants other than GHG emissions.

This air pollution policy has been demonstrated as effective since many EU countries have reduced their air emissions in the last decade.

But there are other areas or important countries, such as China or the USA, where the air pollutant emissions other than GHG are still really high.

These differences among countries in terms of air pollutant emissions and air policy have negative effects on international competitiveness. When the air emissions embodied in international trade are considered, it so happens that in those countries where no air pollutant policies have been put in place, the emissions embodied in exports are higher than those embodied in imports [76]. Therefore, areas such as the European Union are provoking more air pollution through its consumption pattern than from its production. Conversely, countries such as China and India are provoking more air pollution through their production than from their consumption pattern.

This different behavior of countries in relation to air pollution policy makes it difficult to reach an agreement in this field. Those countries with more pollution because of their consumption pattern ask for an agreement based on the production perspective, and those countries with more pollution because of their production ask for an agreement from the consumption perspective. Therefore, an international or global agreement is required if we are seeking a real solution.

As an alternative to the global agreement, the reduction in air pollution, besides the diminishing of GHG emissions, could be reached thanks to the deployment of RE sources. This is why most of the countries' efforts are not only aimed at reaching agreement on emissions, but also most of their public policies are aimed at promoting the use of renewable energy and improving energy efficiency.

The European Directive 20-20-20 goes in this direction. The countries' efforts up to 2020 should be directed to reducing GHG emissions, increasing the RE sources percentage in energy consumption, and improving energy efficiency. This strategy has been confirmed in the Roadmap to 2050.

One final idea comes into our discussion. Scientific research in different fields should help to transform the negative effects that air pollution and GHG emissions have on human health in terms of a homogenous unit of human health (or damage). This information will contribute to policy makers being able to decide the best combination of energy sources among those available, in terms of their effects on human health.

5. Conclusions

The important deployment of RE sources from an international perspective is a fact. The last reports of [11, 12] show the importance that the RE source are achieving in most countries. Although some differences are found, most countries have developed these energy sources with the aim of contributing to reducing the effects of climate change, and therefore, to reaching international commitments. Nevertheless, there are other reasons that arise which explain the deployment of RE sources.

The advantages of using RE sources are of a different nature. Firstly, from an economic perspective, the RE sources allow countries to reduce the energy dependency on fossil fuels. As at least one renewable source is available in all countries, they are a real alternative to fossil fuels. However, the development of RE sources also requires an important investment that creates job opportunities and improves new technologies. The research papers that link productive sectors and the environment are becoming more frequent. The results provide interesting information about which are the main pollutant sectors. The life cycle assessment (LCA) techniques and the input-output models might provide further information on this issue. Secondly, from the epidemiological point of view, research papers show evidence about the effects that air pollutants have on human health. Many efforts have recently been made by scientific researchers from different fields in order to display the negative effects that the different pollutants have on human health, provoking cardiovascular and respiratory diseases. The conclusions are different depending on the country and city considered, or depending on the pollutant and the other variables included in the analysis. But all of them have found that air pollutants have negative effects on human health, and have attempted to quantify them. The final step, that not all researchers follow, is to transform these negative effects into monetary units in order to be suitable for policy makers.

Therefore, the main results of those research papers with different techniques show that the most pollutant sectors from the climate change and epidemiological point of views are quite similar. They are mainly the transport and power generation sectors.

Research papers about the avoided CO_2 and air pollutant emissions that will happen due to the substitution of fossil fuels by RE sources (such as was done in [75]) will contribute to estimate the benefits of RE in terms of emissions. Additionally, a second step is needed. More studies should be carried out in order to quantify the effects on health that provoke this reduction on CO2 and air pollutant emissions due to RE sources (here the epidemiological studies have an important role).

Policy makers have to take into consideration all these positive externalities of RE sources, when evaluating the possibility of their promotion. However, this evaluation should also take into consideration that not all RE sources have equivalent positive effects. Therefore, our recommendation is that governments should be supported by recent research when deciding the most appropriate energy mix for a country.

Acknowledgements

The authors are grateful for the funding provided by the ECO2014-56399-R Project of Spanish Ministry of Economy and Competitiveness, the SEJ-132 project and the support of the Roger Torné Foundation through the Energy and Environmental Economics Chair at the University of Seville.

Author details

María del P. Pablo-Romero*, Rocío Román, Antonio Sánchez-Braza and Rocío Yñiguez

*Address all correspondence to: mpablorom@us.es

University of Seville, Seville, Spain

References

[1] Stern, N. (Ed.). (2007). The economics of climate change: The Stern review. Cambridge University press, New York.

[2] Dell, M., Jones, B. F., Olken, B. A. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, *4*(3), 66–95.

[3] Akachi, Y., Goodman, D., Parker, D. (2009). Global climate change and child health: A review of pathways, impacts and measures to improve the evidence base. UNICEF Innocenti Research Centre, Florence.

[4] Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., Friel, S., Groce, N., et al. (2009). Managing the health effects of climate change. *The Lancet*, 373(9676), 1693–1733.

[5] McMichael, A. J., Bertollini, R. (2011). Risks to human health, present and future. In *Climate Change: Global Risks, Challenges and Decisions*, K. Richardson et al. (eds.), pp. 114–116. Cambridge University Press, New York.

[6] GEA (2012). Global energy assessment – toward a sustainable future. Cambridge University Press, Cambridge, UK, and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria.

[7] Hansen, J. E. (2007). Scientific reticence and sea level rise. *Environmental Research Letters*, 2(2), 024002 (6 pp).

[8] Allison, I., Bindoff, N. L., Bindschadler, R. A., Cox, P. A., de Noblet, N., England, M. H., Francis, J. E., Gruber, N., et al. (2009). The copenhagen diagnosis. Updating the world on the latest climate science. The University of New South Wales Climate Change Research Centre (CCRC), Sydney.

[9] Lund, H., Mathiesen, B. V. (2009). Energy system analysis of 100% renewable energy systems—The case of Denmark in years 2030 and 2050. *Energy*, 34(5), 524–531.

[10] Gschwind, B., Lefevre, M., Blanc, I., Ranchin, T., Wyrwa, A., Drebszok, K., Cofala, J., Fuss, S. (2014). Including the temporal change in $PM_{2.5}$ concentration in the assess-

ment of human health impact: Illustration with renewable energy scenarios to 2050. *Environmental Impact Assessment Review*, in press.

[11] IRENA (2014). Remap2030 – A renewable energy roadmap. International Renewable Energy Agency, IRENA Innovation Technology Centre, Bonn.

[12] IEA (2014a). Renewable energy medium-term market report. International Energy Agency (IEA), OECD, Paris.

[13] REN21 (2014). Renewable 2014 global status report. Renewable energy policy network for the 21st Century. REN21 Steering Committee, Paris.

[14] IEA (2014b). World energy outlook. International Energy Agency (IEA), OECD, Paris.

[15] IEA (2014c). CO2 emissions from fuel combustion. International Energy Agency (IEA), OECD, Paris.

[16] IPCC (2013). Fifth assessment report (AR%). Climate change 2013 – The physical science basis. Cambridge University Press, New York.

[17] IPCC (2007). Climate change 2007: Impacts, adaptation and vulnerability. Cambridge University Press, New York.

[18] WHO (2009). Global health risks: Mortality and burden of disease attributable to selected major risks. World Health Organization (WHO), Regional Office for Europe, Copenhagen.

[19] Campbell-Lendrum, D., Woodruff, R. (2007). Climate change: Quantifying the health impact at national and local levels. WHO environmental burden of disease series No. 14, World Health Organization, Geneva.

[20] EHP (2010). A human health perspective on climate change: A report outlining the research needs on the human health effects of climate change. Environmental Health Perspectives (EHP) and National Institute of Environmental Health Sciences, Research Triangle Park, NC.

[21] D'Amato G., Cecchi, L. (2008). Effects of climate change on environmental factors in respiratory allergic diseases. *Clinical and Experimental Allergy*, 38(8), 1264–1274.

[22] Macdonald, R. W., Mackay, D., Li, Y. -F., Hickie, B. (2003). How will global climate change affect risks from long-range transport of persistent organic pollutants?. *Human and Ecological Risk Assessment*, 9(3), 643–660.

[23] Tucker, M. A. (2009). Melanoma epidemiology. *Hematology/Oncology Clinics of North America*, 23(3), 383–395.

[24] Ebi, K. L., Exuzides, K. A., Lau, E., Kelsh, M., Barnston, A. (2004). Weather changes associated with hospitalizations for cardiovascular diseases and stroke in California, 1983–1998. *International Journal of Biometeorology*, 49(1), 48–58.

[25] Schwartz, J., Samet, J. M., Patz, J. A. (2004). Hospital admissions for heart disease: The effects of temperature and humidity. *Epidemiology*, 15(6), 755–761.

[26] Morabito, M., Modesti, P. A., Cecchi, L., Crisci, A., Orlandini, S., Maracchi, G., Gensini, G. F. (2005). Relationships between weather and myocardial infarction: A biometeorological approach. *International Journal of Cardiology*, 105(3), 288–293.

[27] Barnett, A. G. (2007). Temperature and cardiovascular deaths in the US elderly: Changes over time. *Epidemiology*, 18(3), 369–372.

[28] Kysely, J., Pokorna, L., Kyncl, J., Kriz, B. (2009). Excess cardiovascular mortality associated with cold spells in the Czech Republic. *BMC Public Health*, 9, 1–19.

[29] Gong, H. Jr., Wong, R., Sarma, R. J., Linn, W. S., Sullivan, E. D., Shamoo D. A., Anderson K. R., Prasad, S. B. (1998). Cardiovascular effects of ozone exposure in human volunteers. *American Journal of Respiratory and Critical Care Medicine*, 158(2), 538–546.

[30] Ren, C., Williams, G. M., Morawska, L., Mengersen, K., Tong, S. (2008). Ozone modifies associations between temperature and cardiovascular mortality: Analysis of the NMMAPS data. *Occupational and Environmental Medicine*, 65(4), 255–260.

[31] Pope, C. A., Dockery, D. W. (2006). Health effects of fine particulate air pollution: Lines that connect. *Journal of the Air & Waste Management Association*, 56(6), 709–742.

[32] Jerrett, M., Burnett, R. T., Pope, C. A., Ito, K., Thurston, G., Krewski, D., Shi, Y., Calle, E., Thun, M. (2009). Long-term ozone exposure and mortality. *The New England Journal of Medicine*, 360(11), 1085–1095.

[33] Krousel-Wood, M. A., Islam, T., Muntner, P., Stanley, E., Phillips, A., Webber, L. S., Frohlich, E. D., Re, R. N. (2008). Medication adherence in older clinic patients with hypertension after Hurricane Katrina: Implications for clinical practice and disaster management. *The American Journal of the Medical Sciences*, 336(2), 99-104.

[34] Carod-Artal, F. J. (2007). Strokes caused by infection in the tropics (Ictus de causa infecciosa en el trópico). *Revista de Neurología*, 44(12), 755-763.

[35] US Food and Drug Administration (2005). Quantitative risk assessment on the public health impact of pathogenic vibrio parahaemolyticus in raw oysters. Center for Food Safety and Applied Nutrition (CFSAN), Food and Drug Administration, College Park, MD.

[36] Lake, I. R., Gillespie, I. A., Bentham, G., Nichols, G. L., Lane, C., Adak, G. K., Threlfall, E. J. (2009). A re-evaluation of the impact of temperature and climate change on foodborne illness. *Epidemiology and Infection*, 137(11), 1538–1547.

[37] Kovats, R. S., Hajat, S. (2008). Heat stress and public health: A critical review. *Annual Review of Public Health*, 29, 41-55.

[38] Luber, G., McGeehin, M. (2008). Climate change and extreme heat events. *American Journal of Preventive Medicine*, 35(5), 429-435.

[39] Cohn, B. A., Cirillo, P. M., Wolff, M. S., Schwingl, P. J., Cohen, R. D., Sholtz, R. I., Ferrara, A., Christianson, R. E., van den Berg, B. J., Siiteri, P. K. (2003). DDT and DDE exposure in mothers and time to pregnancy in daughters. *The Lancet*, 361(9376), 2205-2206.

[40] Roeleveld, N., Bretveld, R. (2008). The impact of pesticides on male fertility. *Current Opinion in Obstetrics and Gynecology*, 20(3), 229-233.

[41] Law, D. C. G., Klebanoff, M. A., Brock, J. W., Dunsuno, D. B., Longnecker, M. P. (2005). Maternal serum levels of polychlorinated biphenyls and 1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene (DDE) and time to pregnancy. *American Journal of Epidemiology*, 162(6), 523-532.

[42] Longnecker, M. P., Klebanoff, M. A., Dunson, D. B., Guo, X., Chen, Z., Zhou, H., Brock, J. W. (2005). Maternal serum level of the DDT metabolite DDE in relation to fetal loss in previous pregnancies. *Environmental Research*, 97(2), 127-133.

[43] Ribas-Fitó, N., Gladen, B. C., Brock, J. W., Klebanoff, M. A., Longnecker, M. P. (2006). Prenatal exposure to 1,1-dichloro-2,2-bis (*p*-chlorophenyl)ethylene (*p,p'*-DDE) in relation to child growth. *International Journal of Epidemiology*, 35(4), 853-858.

[44] Fritze, J. G., Blashki, G. A., Burke, S., Wiseman, J. (2008). Hope, despair and transformation: Climate change and the promotion of mental health and wellbeing. *International Journal of Mental Health Systems*, 2, 1-13.

[45] Lefebvre, K. A., Tilton, S. C., Bammler, T. K., Beyer, R. P., Srinouanprachan, S., Stapleton, P. L., Farin, F. M., Gallagher, E. P. (2009). Gene expression profiles in zebrafish brain after acute exposure to domoic acid at symptomatic and asymptomatic doses. *Toxicology Science*, 107(1), 65-77.

[46] Curriero, F. C., Patz, J. A., Rose, J. B., Lele, S. (2001). The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948-1994. *American Journal of Public Health*, 91(8), 1194-1199.

[47] Dell, M., Jones, B. F., Olken, B. A. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, 4(3), 66-95.

[48] Cancun Agreements (2010). Cancun agreements. United Nations Framework Convention on Climate Change (UNFCCC), Cancun.

[49] Hamilton, L. D. (2011) Energy and health. In *53. Environmental Health Hazards, Encyclopedia of Occupational Health and Safety*, T. Kjellström and A. Yassi (Chapter Editors), J. M. Stellman (Editor-in-Chief). International Labor Organization, Geneva.

[50] IPCC (2012). Renewable energy sources and climate change mitigation. Cambridge University Press, New York.

[51] Treyer, K., Bauer, C., Simons, A. (2014). Human health impacts in the life cycle of future European electricity generation. *Energy Policy*, Vol. 74, Supplement 1, pp. S31-S44.

[52] WHO (2006). Air quality guidelines. Global update 2005. Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. World Health Organization (WHO), Regional Office for Europe, Copenhagen.

[53] Zah, R., Böni, H., Gauch, M., Hischier, R., Lehmann, M., Wäger, P. (2007). Ökobilanz von Energieprodukten: Ökologische Bewertung von Biotreibstoffen. Bundesamtes für Energie, Bundesamt für Umwelt, Bundesamt für andwirtschaft, Bern, Switzerland.

[54] Notter, D. A., Gauch, M., Widmer, R., Wager, P., Stamp, A., Zah, R., Althaus, H. J. (2010). Contribution of li-ion batteries to the environmental impact of electric vehicles. *Environmental Science & Technology*, 44(17), 6550-6556.

[55] Zackrisson, M., Avellan, L., Orlenius, J. (2010). Life cycle assessment of lithium-ion batteries for plug-in hybrid electric vehicles – Critical issues. *Journal of Cleaner Production*, 18(15), 1519-1529.

[56] Ezzati, M., Bailis, R., Kammen, D. M., Holloway, T., Price, L., Cifuentes, L. A., Barnes, B., Chaurey, A., Dhanapala, K. N. (2004). Energy management and global health. *Annual Review of Environment and Resources*, 29(1), 383-419.

[57] Curtis, L., Rea, W., Smith-Willis, P., Fenyves, E., Pan, Y. (2006). Adverse health effects of outdoor air pollutants. *Environment International*, 32(6), 815-830.

[58] Paul, W., Kirk, R. S., Michael, J., Andrew H. (2007). A global perspective on energy: Health effects and injustices. *The Lancet*, 370(9591), 965-978.

[59] WHO (2014). Promoting health while mitigating climate change. World Health Organization (WHO), Regional Office for Europe, Copenhagen.

[60] Masera, O. R., Saatkamp, B. D., Kammen, D. M. (2000). From linear fuel switching to multiple cooking strategies: A critique and alternative to the energy ladder model. *World Development*, 28(12), 2083-2103.

[61] Smith, K. R., Pillarisetti, A. (2012). A short history of woodsmoke and implications for Chile (Breve historia del humo de leña y sus implicaciones para Chile). *Estudios Públicos*, 126, 163-179.

[62] Jetter, J., Zhao, Y., Smith, K. R., Khan, B., Yelverton, T., DeCarlo, P., Hays, M. D. (2012). Pollutant emissions and energy efficiency under controlled conditions for household biomass cookstoves and implications for metrics useful in setting international test standards. *Environmental Science & Technology*, 46(19), 10827-10834.

[63] Smith, K. R., Frumkin, H., Balakrishnan, K., Butler, C. D., Chafe, Z. A., Fairlie, I., Kinney, P., Kjellstrom, T., Mauzerall, D. L., McKone, T. E., McMichael, A. J., Schneider, M. (2013). Annual Review of Public Health, 34, 159-188.

[64] Naeher, L. P., Brauer, M., Lipsett, M., Zelikoff, J. T., Simpson, C. D., Koenig, J. Q., Smith, K. R. (2007). Woodsmoke health effects: A review. *Inhalation Toxicology*, 19(1), 67-106.

[65] USEPA (2011). Assessing the multiple benefits of clean energy. A resource for states. State and local climate and energy program, EPA-430-R-11-014. United States Environmental Protection Agency, Washington, D. C.

[66] Haberl, J., Culp, C., Yazdani, B., Gilman, D., Fitzpatrick, T., Muns, S., Verdict, M., Ahmed, M., Liu, Z., Baltazer-Cervantes, J., Bryant, J., Degelman, L., Turner, D. (2004). Energy efficiency/renewable energy impact in the Texas Emissions Reduction Plan (TERP). ESL-TR-04/12-01. The Energy Systems Laboratory, Texas Engineering Experiment Station, Austin, TX.

[67] USEPA (2007). Technology transfer network clearinghouse for inventories & emissions factors. Emission Inventory Improvement Program. United States Environmental Protection Agency, Washington, D. C.

[68] Wisconsin Public Service Commission (2007). Public service commission of wisconsin focus on energy evaluation semiannual report (FY07, Year-end). Wisconsin Public Service Commission, Madison, Wisconsin.

[69] Sommer, H., Künzli, N., Seethaler, R., Chanel, O., Herry, M., Masson, S., Vergnaud, J. –C., Filliger, P., Horak, Jr. F., Kaiser, R., Medina, S., Puybonnieux-Texier, V., Quénel, P., Schneider, J., Studnicka, M. (2000). Economic evaluation of health impacts due to road traffic-related air pollution – An impact assessment project of Austria, France, and Switzerland. In IPCC Workshop on Assessing the Ancillary Benefits and Costs of Greenhouse Gas Mitigation Strategies, Washington DC.

[70] Pablo-Romero, M. D. P., Román, R., Gonzalez Limón, J. M., Praena-Crespo, M. (2014). Effects of fine Particles 2.5 on children's hospital admissions for respiratory health in Seville (Spain). *Journal of the Air & Waste Management Association*, in press.

[71] Pervin, T., Gerdtham, U. G., Lyttkens, C. H. (2008). Societal costs of air pollution-related health hazards: A review of methods and results. *Cost Effectiveness and Resource Allocation*, 6(19), 1-22.

[72] Gschwind, B., Lefevre, M., Blanc, I., Ranchin, T., Wyrwa, A. (2015). Including the temporal change in $PM_{2.5}$ concentration in the assessment of human health impact: Illustration with renewable energy scenarios to 2050. Environmental Impact Assessment Review, 52, 62–68.

[73] Mathiesen, B.V., Lund, H., Karlsson, K. (2011). 100% Renewable energy systems, climate mitigation and economic growth. *Applied Energy*, 88(2), 488-501.

[74] Partridge, I., Gamkhar, S. (2012). A methodology for estimating health benefits of electricity generation using renewable technologies. *Environment International*, 39(1), 103-110.

[75] García, A., Román, R. (2013). An economic valuation of renewable electricity promoted by feed-in system in Spain. Renewable Energy, 68, 51-57.

[76] Román, R., Cansino, JM., Rueda-Cantuche, JM. (2013). An air emissions analysis from the consumption perspective in EU-27. A Multi-Regional Input-Output model. V Spanish conference in Input-Output Analysis. Seville, 18-20 September.