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RESEARCH ARTICLE

Monetization of the environmental damage caused by fossil fuels

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Abstract

Fossil fuels account for more than 80% of the world's energy consumption. Constituents of the atmosphere have changed perceptibly due to the increased use of fossil fuels. Therefore, many researchers have tried to relate their effect on society. In Pakistan, fossil fuel consumption and its CO_2-based emission factor have been significantly correlated to economic growth. However, it needs further attention to study the adverse effects of fossil fuels. This study is an attempt to assess the cost of fossil fuels to society. Damages caused by fossil fuels are evaluated for the years of 2005–2009, using local pollution factors based on CO_2 emission. Results show that the market price of fossil fuels increases after adding up the cost of damage caused by the final use of the fuel. People pay a huge amount of PKR 133 billion per year for taxes, health services, insurance premiums, and low living standards. Accordingly, it is suggested that we must shift from fossil fuels to other alternative clean types of energy.

Keywords Fossil fuels · Adverse effects · Extent of damage · CO_2 emission · Monetization · Pakistan

Introduction

Energy plays a vital role in the economic growth of societies. Today, most of the world's energy needs are met by fossil fuels. On a global scale, 80% of energy is created from fossil fuels (World Bank 2006). The World Energy Outlook (WEO) 2014 estimated that over the period following up to 2040, total energy demand is expected to grow by almost 40%, while the contribution of fossil fuels to the total amount of energy produced by various sources drops. However, fossil fuels remain the dominant energy source, with petroleum, coal, and natural gas, found to correspond to about one quarter of the world energy requirements (Cronshaw 2015). At the same time, though, fossil fuels are considered one of the main sources of environmental pollution worldwide. Combustion, which is related to the most serious environmental problems, is the intended purpose of all fossil fuels, regardless of its result (i.e., heat, mechanical energy, or generation of electricity).

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The composition of the atmosphere has changed significantly in the current century on account of the increased use of fossil fuels (Kampa and Castanas 2008).

Fossil fuels are mainly composed of carbon and hydrogen, with a little amount of sulfur. Yet, in the process of refining, lead and alcohols are also added. The ultimate use of fossil fuels releases many elements (Bertine and Goldberg 1971), compounds (CO_x, SO_x, CH), soot, and other organic bulk into the atmosphere, which finally cause environmental pollution (Barbir et al. 1990).

The long-term exposure to these gases (CO, CO_2, NO_2, and SO_2) has devastating effects on human beings, which are manifested as fatal lung and cardiovascular diseases (Clark et al. 1989). Carbon monoxide and carbon dioxide cause cellular anoxia, hyperventilation, and asphyxia. Pulmonary edema can occur when the amount of inhaled ozone increases. Similarly, nitrogen and sulfur oxides cause pulmonary edema and even death (Sher 1998).

According to the modeled ambient air pollution data for 2015, Lelieveld observed that the mean loss of life expectancy (LLE) due to air pollution strongly exceeds that owing to violence (all forms together), i.e., by an order of magnitude (LLE is 2.9 and 0.3 years, respectively) (Lelieveld et al. 2020).

Sulfur and nitrogen oxides dissolve in clouds and in raindrops form sulfuric acid and nitric acid, which in turn cause acid rain (Likens et al. 1979) and acid snow (Likens and

Bormann 1974). The diluted carbonic acid has negligible acidifying effects (Record et al. 1982). Acidic deposition in soil and water (Krug and Frink 1983) has adversely affected aquatic and terrestrial ecosystems, afflicting people, animals, vegetation, cultural heritage, and historic ecosystems (Zhao and Sun 1986).

Carbon dioxide, methane, nitrogen oxide, and chlorofluorocarbons (CFC) are anthropogenic greenhouse gases (De Klein et al. 2008), which cause global warming (Samimi and Zarinabadi 2012). The temperature rise, melting glaciers, sea-level rise, and a range of other impacts of climatic change, such as droughts, floods, hurricanes, and forest fires, are the consequences of global warming (Barnett et al. 2005; Gustafson et al. 2020).

Removing subsidies on fossil fuels may help to mitigate the effects of climate change by preventing inefficient energy use (Jewell et al. 2018). Globally, the fossil fuel subsidies remained large at $4.7 trillion (6.3% of global GDP) in 2015 and are presented at $5.2 trillion (6.5% of GDP) in 2017. The fossil fuel subsidies in Pakistan were US$ 18 billion in 2015. Undoubtedly, coal has the highest subsidy share (44%), followed by oil (41%), natural gas (10%), and electric power (4%). The estimated cost of coal for global warming was around US$ 4 GJ^{-1}, and for Pakistan, it was estimated at US$ 5 GJ^{-1} (Coady et al. 2019).

Ghauri et al. (2007) reported a concentration of PM_{10} around 200 μg/m^3 in major cities of Pakistan. This value far exceeds the World Health Organization (WHO) interim target of 70 μg/m^3 (Ghauri et al. 2007). The six major cities of Quetta, Karachi, Rawalpindi, Lahore, Peshawar, and Islamabad had been reported with a CO concentration of around 8.1, 5.8, 4.6, 4.6, 3.5, and 3.5 μg/m^3, respectively, during the day time (Colbeck et al. 2010).

An analysis of data collected within a period of 4 years (2007–2010) showed high concentration of fine particulate matter ($PM_{2.5}$) in Lahore (143 μg/m^3), Peshawar (71 μg/m^3), Karachi (88 μg/m^3), Islamabad (61 μg/m^3), and Quetta (49 μg/m^3) (Sanchez-Triana et al. 2014).

The 4-year (2007–2010) time series analysis of sulfur dioxide (SO_2) showed that the city of Lahore, with a daily concentration of 309 μg/m^3, had an annual SO_2 concentration of about 74 μg/m^3. The most populous *metropolitan* areas, like Quetta, Karachi, and Peshawar, were reported with SO_2 concentration of around 54, 34, and 39 μg/m^3, respectively. Generally, SO_2 values were elevated throughout the study period (2007–2010).

During the same period, the annual concentrations of nitrogen dioxide (NO_2) in Peshawar, Islamabad, Lahore, and Karachi were reported as 52, 49, 49, and 46 μg/m^3, respectively, which exceed the safety limit of WHO air-quality-guideline value of 40 μg/m^3. Quetta was found with a lower concentration of 37 μg/m^3. The concentrations of O_3 and CO were reported within the permissible limits of WHO (WHO guideline values).

The strong correlation between $PM_{2.5}$ and CO suggested that road traffic was the main source of fine PM in Pakistan (Sanchez-Triana et al. 2014).

The following approaches were used to estimate the adverse effects of fossil fuels, depending on the nature of the damage and the availability of the data:

(1) Estimate of direct damage proportionate to physical effect
(2) Estimation of the cost of damage reduction, either as a form of remedy, or as a prevention measure

In this study, the negative impact costs were assessed on an annual basis in the PKR for the data available this year and were normalized to the reference year (2009), using implicit deflators. Next, the cost per unit of energy consumed (PKR/GJ) was calculated for all fossil fuels. These additional costs of fuel used were then included in the existing commercial costs of fossil fuels. Thus, the real cost of fossil fuels (the price paid by society) was estimated.

Estimate of damage

Fossil fuels have many detrimental environmental effects, but in the present study, we have considered only the two negative effects, i.e., impact on humans and agriculture.

Impact on humans

The impact of air pollution on humans is difficult to define, since clinical diseases and mortality of exposed populations have not been calculated in significant numbers. Some qualitatively defined adverse effects of environmental pollution need to be quantified. Hence, there is a debate among the environmentalists on the quantification of the adverse effects on animals and plants (Lave and Seskin 1973). The majority of the exposed population has less severe symptoms; consequently, a specific laboratory is needed to quantify the results. In addition, people respond differently to these effects, and sometimes the severe effects cannot be diagnosed.

Pollutants, such as carbon monoxide, sulfur and nitrogen oxides, hydrocarbons, and particulate matter cause lung cancer and even death (Seaton et al. 1995). The synergistic effects between various primary pollutants and the secondary pollutants they generate, such as ozone, acid mist and acid rain, significantly increase these effects (Trasande and Thurston 2005).

Medical research reveals a high level of premature mortality in polluted regions (Brunekreef and Holgate 2002). The American Lung Association has reported 115 million Americans who are exposed to dangerous levels of air pollution. Every year, 50,000 people die prematurely in North America (Luoma 1988). The American Cancer Society

(ACS) and the Chemical Industry Association (CMA) estimate the contribution of pollution to total cancer mortality at 2% (Sanchez-Triana et al. 2014). In 1990, Barbir analyzed environmental data in the USA for the period between 1960 and 1985 and reported that malignant neoplasms of the respiratory and laryngeal organs cause chronic obstructive pulmonary diseases, which results in high death rate.

Although the mortality among 100,000 people was reported as 954.7 in 1960 and 873.9 in 1985, the death rate due to the aforesaid diseases increased from 32.1 to 84.6 during that period (from 1960 to 1985) (Barbir et al. 1990). It should be noted, at this point, that innovations in medicine and tobacco control have increased life expectancy. Therefore, a high mortality rate was associated to air pollution. Considering that the mortality rate in 1960 is the "normal mortality rate", which was 52.5 (84.6 to 32.1) deaths per 100,000 persons, the increase in mortality, recorded in 1985 (125,000 deaths), was a result of air pollution.

Zweig reported that the cost of human life is between $300,000 and $500,000, which reflects an annual damage of $50 billion to society (Zweig 1982). Premature death was regarded as the most costly consequence of air pollution for humans (Lelieveld et al. 2015). Medical expenses for fatal and non-fatal respiratory diseases and for diseases related to eye and skin irritation and to cancer were attributed to air pollution (Schikowski and Hüls 2020). These expenses approximately constitute 12% of the total amount (Awad and Veziroğlu 1984), which is a cost of US$ 422.6 billion (Barbir et al. 1990). Private and public expenditure, health services, medical research, and infrastructure increase the damage to society by an additional amount of US$ 50 billion per year. Unrecorded illnesses and discomfort affecting labor efficiency are undetectable negative effects of air pollution on humans, as well. The reported value is a 2% decrease in labor productivity (Awad and Veziroğlu 1984), which accounts for a US$ 47.4 billion loss to the income of persons living on a salary (Barbir et al. 1990). In the context of the aforementioned discussion, the total cost of human exposure in 1985 was estimated approximately as US$ 147.4 billion.

The economic cost of air pollution to human health in Pakistan is estimated at 94%, with 71% being linked to premature death and 23% related to morbidity (Muller and Mendelsohn 2007). During 19 years of research (1992–2010), $PM_{2.5}$ and O_3 were identified as the main causes of financial hardship due to air pollution (Eklund et al. 2014; World Health Organization 2006; Pope III et al. 2002). Nevertheless, in South Asia and worldwide, $PM_{2.5}$ has been found more dangerous than O_3 (OECD 2008; UNAIDS 2006).

Kolbek, Zahir, and Zulfikar have declared PM as the main pollutant and responsible for the financial distress, caused by its negative impact on human health in Pakistan (Colbeck et al. 2010). The $PM_{2.5}$ concentration causes more than 9000 premature deaths annually, accounting for 20% of deaths caused by Acute Lower Respiratory Tract Infection (ALRTI) among children under five, 24% of cardiovascular mortality, and 41% of deaths among people of 30 years of age and above, suffering from respiratory tract malignant neoplasms in these cities.

In Karachi, approximately 12% of mortality was reported among children under 5 years of age and 88% among adults (Ostro 2004; Pope et al. 2009; Pope III et al. 2002). The annual concentration of particulate matter was considered the cause of 59% of chronic bronchitis in these cities. This includes 185,000 cases of chronic bronchitis, almost 33,000 hospital admissions, more than 645,000 emergency room visits, more than 1.6 million ALRI cases in children, and more than 300 million respiratory symptoms (Abbey et al. 1995; Ostro 1994).

Although the individual health impact ascribed to sources of pollution is complex, a clear connection exists between air pollution caused by fossil fuel combustion and health (Jiménez et al. 2015). Coady et al. have estimated that reducing the level of subsidy for fossil fuels and imposing taxes on them will slash premature deaths brought on by air pollution by more than half (Coady et al. 2015).

In 2005, premature deaths, cardiovascular and pulmonary diseases, and lower respiratory infection (LRI) in children were attributed to adverse environmental effects estimated around US$ 1.07 billion (World Bank 2008). During the same year, more than 22,600 mortalities, including 80,000 children under the age of five, were ascribed to air pollution (World Bank 2008; World Health Organization 2006). More than 80,000 hospital admissions were registered in 2007, including 8000 cases of chronic bronchitis and 5 million cases of lower respiratory diseases in children under 5 years of age (World Health Organization 2009).

In 2007, the government of Punjab (in Pakistan) paid a total of PKR 35 billion for 83% mortality and 17% morbidity cases on account of polluted air. In 2009, the Sindh (Pakistan) government paid a total of PKR 53 billion for health effects due to air pollution (Sanchez-Triana et al. 2014).

Impact on agriculture

Polluted air causes damage to plants, resulting in heavy crop loss. Plants are directly affected by sulfur oxides, nitrogen oxides, and ozone. Ozone concentration affects the economic value of Pakistan's most important crops. Crop growth has been studied on three different plots in a controlled environment (charcoal-filtered air, unfiltered air, and chambered field plots) (Wahid 2006). Seed yield reduction was reported, ranging from 18 to 43% for three different wheat varieties. Following the same methodology, Ahmed (2009) found a greater loss for two types of mung beans (47–51%) (Ahmed

2009). The financial cost of O_3 damage to crops has been estimated at US$ 550 million (Van Dingenen et al. 2009).

To date, no major energy source, either non-renewable or renewable, has been abolished owing to economic or environmental constraints (Chow et al. 2003; Shahbaz et al. 2012a, b). Fossil fuels CO_2 emission has been significantly correlated to the economic growth of the global panel of 58 countries (Saidi and Hammami 2015).

In Pakistan, a strong relationship has been reported between fossil fuel CO_2 emissions, energy consumption, and economic growth (Shahbaz et al. 2012a, b). Expenditure of energy is rising almost everywhere; energy production and consumption are increasing and have a significant impact on the environment globally (Holdren 1991). The cost of these effects is not included in the commercial cost of fossil fuels. Ultimately, the public pays for these expenses, because they have to withstand the worst of the unbalanced ecosystem. Accordingly, an initiative was taken to study the negative impacts of fossil fuels and to find an alternative solution.

The reduction policy based on the rollback-to-a-standard method can be preferred for peak concentrations. The increasing concentration of $PM_{2.5}$ in the environment is a common problem of serious concern for all people, and hence, it must be given top priority (Anjum et al. 2020).

In many places around the world, such as in South Asia, including Pakistan, $PM_{2.5}$ concentration in the environment has exceeded the standardized limit of the World Health Organization (WHO) Air Quality Index (AQI). The National Environmental Quality Standards Authority (NEQS) announced the daily and annual 24-h mean values of $PM_{2.5}$ concentrations as 40 and 25 $\mu g\ m^{-3}$, respectively, which were revised as 35 and 15 $\mu g\ m^{-3}$, respectively (Pak-EPA 2010). It has been observed that many deaths can be avoided by reducing the exceeding levels of $PM_{2.5}$ to the hypothetical alternative $PM_{2.5}$ standard of 15 $\mu g\ m^{-3}$ (US-EPA 2020).

A stepwise conversion from the conventional energy system to a clean and renewable solar energy based hydrogen energy system is indispensable to safeguard our environment and to ensure enough future energy supply.

Monetization methods

Various methods and approaches have been adopted all around the globe to monetize the detrimental effects of fossil fuels. Gibbs and Steen developed the Environmental Priorities Strategies (EPS) model to facilitate comparison of environmental impacts among product concepts in product development (Gibbs Jr and Steen 1999). An external costs of energy (ExternE) model has also been adopted to monetize socio-environmental damage (Bickel and Friedrich 2005). Similarly, Ecotax is another European monetary valuation method, where the weighting factors are derived based on environmental taxes and fees in Sweden (Eldh and Johansson 2006). Weidema developed the Stepwise2006 approach to remove the previous imperfection in monetizing a great extent of damage to the environment and improved cost-benefit analysis (Weidema 2009).

The LCIA approach, known as the Life Cycle Impact Assessment Method, based on Endpoint Modeling (LIME), was used for impact assessment, using Japanese context data by choosing correct protocols from LCIA's three main steps: classification, damage evaluation, and weighting (Itsubo et al. 2004). We modified the model, given in the Eqs. (1) and (2), with local pollution factors based on CO_2 emission (the explanation of the symbols follows).

$$C_n = \frac{D_n}{M_n} \tag{1}$$

$$M_n = \sum_{i=1}^{3} (F_i P_{\text{in}}) \tag{2}$$

All three types of fossil fuels are available in our local area with different carbon contents. Hence, the pollution factors, which we have calculated, are different than those calculated by other researchers, e.g., Barbir et al. (1990).

The modified model can be sketched as follows. Outputs (C_n, D_n, and M_n) can be produced by the following static Eqs. (1) and (2), where C_n, D_n, and M_n represent the itemized damage, the estimated damage per year, and the modified fossil fuel consumption, respectively. The pollution and fuel consumption factors are represented by P_{in} and F_i, respectively. The specific type of damage is represented by n, and coal, oil, and natural gas are represented by the subscripts (i = 1, 2, 3), respectively.

Data reduction

Coal, natural gas, and oil are classified as fossil fuels. They contribute to environmental damage, regardless of their energy content. Thus, for a specific form of damage due to fossil fuels, P_{in} (a pollution factor) was introduced (Barbir et al. 1990). The factor is taken in proportion to the damage caused by a given type of fuel "i" and for a given type of damage "n." CO_2 emission was used to calculate the pollution factor; i.e., the factor for each fuel is considered proportional to the CO_2 emission per unit of energy of the fuel consumed (Table 1). The amount of CO_2 emitted per million British thermal units (MBtu) of fossil fuel energy has been calculated as 214.3, 161.3, and 117.0 lb. MJ^{-1} for sub-bituminous coal, heating oil, and natural gas, respectively (US-EIA 2020).

The modified fossil fuel consumption (M_n) was calculated about 10^{18} J $year^{-1}$ using Eq. (2).

Table 1 Pollution factors based on CO_2

Amount (Kg) of CO_2 emission GJ^{-1}			
Coal		Petroleum	N. Gas
88.1		69.4	50.0
Pollution factor (P_{in})			
Type of damage (n)	Coal $i = 1$	Petroleum $i = 2$	N. Gas $i = 3$
Damage due to emissions	1.00	0.78	0.56

The itemized types of damage, labeled as C_1, C_2, and C_3, were calculated using the set of the Eqs. (3).

$$\begin{aligned} C_2 &= 75.9,\ \ 24.7,\ \ 56.38,\ \ 0.03 \\ C_1 &= \frac{C_2}{0.78} = 97.31,\ \ 31.67,\ \ 72.28,\ \ 0.04 \\ C_3 &= \frac{C_2}{0.78} \times 0.56 = 54.49,\ \ 17.73,\ \ 40.48,\ \ 0.02 \end{aligned} \quad (3)$$

Results and discussion

Table 2 summarizes all the data, including the annually assessed types of damage, the modified consumption values, the unit damage, and the reference year. Along with Table 2, Fig. 1 depicts the damage divided into parts to be analyzed in relation to the amount of fuel energy used.

The types of damage derived from coal, petroleum, and natural gas have been calculated based on emission factors and per annum consumption of the individual fuel. Since the data is available for the years of 2005–2009, the itemized types of damage were evaluated only for that period.

According to the Energy Year Book 2011 record, all three fuels used are presented in units of tone of oil equivalent (TOE). The amount of natural gas, crude oil, and coal used is (60,216,163), (43,824,267), and (17,058,247) tons of oil equivalent, respectively. Total fuel consumption was modified as "M_n" by multiplying the emission factors of coal, oil, and gas with the total consumed quantity of the fuel. The pollution factors based on CO_2 emission for coal, oil, and gas were calculated as 1.0, 0.7, and 0.56, respectively. The modified fossil fuel consumption in units of 10^{18} $year^{-1}$ was calculated as 0.83, 0.89, 0.94, and 1.0 and a total of 3.661.

Accordingly, based on direct and indirect estimation of the economic cost of damage, an annual cost of PKR 63.00, 22.00, 53.00, and 0.03 trillion, of coal, oil, and gas, respectively, and a gross total of 138.03 trillion were calculated. The individual types of damage calculated per unit energy (GJ^{-1}) of coal, oil, and gas were evaluated as PKR 201.3, 157.1, and 112.72, respectively.

Table 2 Fossil fuel environmental damage estimate

Type of damage	Region (Pakistan)	Year	Fossil Fuel Consumption TOE (Energy Year Book 2011) ("https://hdip.com.pk/docs/important-tables-14-03-2012.pdf,") (Coal)	(Dry natural gas)	(Crude oil)	D_n Damage estimate PKR 10^9 $year^{-1}$	M_n Modified fossil fuel consumption 10^{18} J $year^{-1}$	Environmental Damage 2009 PKR GJ^{-1} Coal (C_{1n}) Itemized damage	Petroleum (C_{2n}) Itemized damage	Natural gas (C_{3n}) Itemized damage
Effects on humans		2005–2006	3,611,490	13,325,251	10,877,601	63	0.831	97.31	75.90	54.49
		2006–2007	4,149,041	14,701,024	10,575,330	22	0.89	31.67	24.7	17.73
		2008–2009	3,893,001	16,307,898	10,842,614	53	.94	72.28	56.38	40.48
Effects on crops		2007–2008	5,404,715	15,881,990	11,528,722	0.03	1	.04	.03	.02
Totals			17,058,247	60,216,163	43,824,267	138.03	3.661	201.3	157.01	112.72

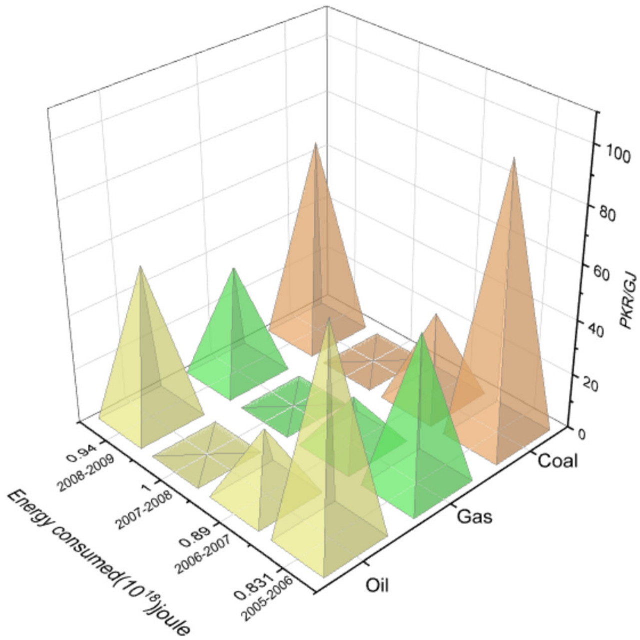

Fig. 1 Estimated itemized types of damage for fossil fuels

The analysis showed that natural gas is used more than the other two fuels (coal and oil), but its damage is less than (that of) the other types of fuel. On the other hand, coal is used less than the others, but its damage is more than that of the other two. This is verified by the dynamic growth model, developed by Nyambuu and Semmler (Nyambuu and Semmler 2020).

In the USA, Barbir et al. reported an environmental damage caused by each of the fossil fuels (coal, oil, and gas) around US$ 3.48, 2.83, and 2.09, respectively. These values were calculated in terms of environmental effects on humans. The environmental effects on agriculture were reported around US$ 1.35, 1.09, and 0.81, respectively (Barbir et al. 1990).

Damage was calculated only for agriculture and humans. Nonetheless, these costs are not included in the market values of fossil fuels. However, the public pays for these types of damage directly in the form of taxes, insurance premiums, and low standards of living and indirectly in the form of health-related issues. If the cost of damage was included in the actual prices of the fossil fuels used, then other alternative clean energies, such as wind, solar, and hydrogen, would be suggested earlier.

Table 2 shows the relative values of fossil fuel consumption and its damage index. It is seen that the ratio between damage and coal, oil, and gas consumption is 42.68 to 13.7%, 33.4 to 35.6%, and 23.8 to 50.7%, respectively. Therefore, in comparison to coal and oil, the attractiveness of natural gas as an environmentally friendly energy source is obvious. This finding would also constitute a strong argument for persuading the public as regards the use of gaseous fuels and, subsequently, for convincing them of the need for a smooth shift to hydrogen, as a gaseous fuel.

Conclusions

Fossil fuel mostly contains petroleum, coal, oil, and natural gas. These products when released in the environment cause damage to human health, animals, forests and plants, aquatic ecosystem, climate change, ozone layer, crops, infrastructures, visibility, and many others.

Environmental damage resulting from each of the fossil fuels were assessed on an item-by-item basis. Data is calculated and evaluated for the years of 2005–2009. We modified the model, given in the Eqs. (1) and (2), with local pollution factors based on CO_2 emission. Table 2 shows total fossil fuel environmental damage, and Fig. 1 depicts estimated itemized types of damage for each of the fossil fuels. The percentage ratio between damage and fossil fuel consumption is 42.68 to 13.7%, 33.4 to 35.6%, and 23.8 to 50.7%, respectively. Therefore, in comparison to other fossil fuels, natural gas is found an environmentally friendly energy source. It has been found that this damage pileup to a very large value of PKR 133 billion per year. This is what the public pays in addition to the commercial cost for using fossil fuels. The estimated value could be further increased by taking in account the actual cost of human suffering and the total cost of possible climate change.

The results of this study unequivocally show that the early adaptation of cleaner energies, such as wind, solar, and hydrogen, will be extremely beneficial to society, economically viable, and environment-friendly.

The findings have very important policy implications, i.e., to minimize the use of fossil fuels, to save the foreign exchange, and to control the environmental damages. Harness of clean energy resources like wind, solar, and hydrogen to make the environment clean and free of pollution is suggested.

A stepwise conversion from the conventional energy system to a clean and renewable solar energy based hydrogen energy system is indispensable to safeguard our environment and to ensure enough future energy supply.

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Data availability All data generated or analyzed during this study are included in this article.

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

Ethical approval

- The manuscript is not submitted to any other journal for simultaneous consideration.
- The submitted work is original and has not been published elsewhere in any form or language.
- The study is not split up into several parts to increase the quantity of submissions and not submitted to various journals or to one journal over time.
- Results are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation (including image based manipulation).
- No data, text, or theories by others are presented as our own, and proper acknowledgments to other works are given.

Consent to participate Not applicable.

Consent to publish Not applicable.

References

Abbey DE, Lebowitz MD, Mills PK, Petersen FF, Beeson WL, Burchette RJ (1995) Long-term ambient concentrations of particulates and oxidants and development of chronic disease in a cohort of non-smoking California residents. Inhal Toxicol 7(1):19–34

Ahmed S (2009) Effects of air pollution on yield of mungbean in Lahore, Pakistan. Pak J Bot 41:1013–1021

Anjum MS, Ali SM, Subhani MA, Anwar MN, Nizami AS, Ashraf U, Khokhar MF (2020) An emerged challenge of air pollution and ever-increasing particulate matter in Pakistan; a critical review. J Hazard Mater:123943. https://doi.org/10.1016/j.jhazmat.2020.123943

Awad A, Veziroğlu TN (1984) Hydrogen versus synthetic fossil fuels. Int J Hydrog Energy 9(5):355–366

Bank, W. (2008). Environmental health and child survival: epidemiology, economics, experiences: World Bank

Barbir F, Veziroğlu T, Plass H Jr (1990) Environmental damage due to fossil fuels use. Int J Hydrog Energy 15(10):739–749

Barnett TP, Adam JC, Lettenmaier DP (2005) Potential impacts of a warming climate on water availability in snow-dominated regions. Nature 438(7066):303–309

Bertine K, Goldberg ED (1971) Fossil fuel combustion and the major sedimentary cycle. Science 173(3993):233–235

Brunekreef B, Holgate ST (2002) Air pollution and health. Lancet 360(9341):1233–1242

Bickel P, Friedric R (2005) Externalities of energy. Methodology 2005 Update. European Commission EUR, 21951. Germany. Institut Fur Energiewirtschaft und Rationelle Energieanwendung - IER Universitat Stuttgart. http://www.externe.info/externe_2006/brussels/methup05a.pdf

Chow J, Kopp RJ, Portney PR (2003) Energy resources and global development. Science 302(5650):1528–1531

Clark RB, Frid C, Attrill M (1989) Marine pollution, vol 4. Clarendon press, Oxford

Coady D, Flamini V, Sears L (2015) The Unequal Benefits of Fuel Subsidies Revisited: evidence for developing countries. IMF Working Papers. WP/15/250

Coady D, Parry I, Le NP, Shang B (2019) Global fossil fuel subsidies remain large: An update based on country-level estimates. IMF Working Papers, 19(89):39

Colbeck I, Nasir ZA, Ali Z (2010) The state of ambient air quality in Pakistan—a review. Environ Sci Pollut Res 17(1):49–63

Cronshaw I (2015) World Energy Outlook 2014 projections to 2040: natural gas and coal trade, and the role of China. Aust J Agric Resour Econ 59(4):571–585

De Klein CAM, Pinares-Patino C, Waghorn GC (2008) Greenhouse gas emissions. In: McDowell RW (ed) Environmental impacts of pasture-based grazing. pp 1–32. https://enviro2.doe.gov.my/ekmc/wp-content/uploads/2018/01/Environmental-impacts-of-pasture.pdf

Eklund AG, Chow JC, Greenbaum DS, Hidy GM, Kleinman MT, Watson JG, Wyzga RE (2014) Public health and components of particulate matter: the changing assessment of black carbon. J Air Waste Manage Assoc 64(11):1221–1231

Eldh P, Johansson J (2006) Weighting in LCA based on ecotaxes-development of a mid-point method and experiences from case studies. Int J Life Cycle Assess 11(1):81–88

Ghauri B, Lodhi A, Mansha M (2007) Development of baseline (air quality) data in Pakistan. Environ Monit Assess 127(1–3):237–252

Gibbs RW Jr, Steen GJ (eds) (1999) Metaphor in cognitive linguistics: selected papers from the 5th international cognitive linguistics conference, Amsterdam, 1997 (vol 175). John Benjamins Publishing, Amsterdam

Gustafson A, Marlon JR, Goldberg MH, Wang X, Ballew MT, Rosenthal SA, Leiserowitz A (2020) Blame where blame is due: many Americans support suing fossil fuel companies for global warming damages. Environ Sci Policy Sustain Dev 62(2):30–35

Holdren JP (1991) Population and the energy problem. Popul Environ 12(3):231–255 https://hdip.com.pk/docs/important-tables-14-03-2012.pdf, https://www.eia.gov/tools/faqs/faq.php?id=73andt=11

Itsubo N, Sakagami M, Washida T, Kokubu K, Inaba A (2004) Weighting across safeguard subjects for LCIA through the application of conjoint analysis. Int J Life Cycle Assess 9(3):196–205

Jewell J, McCollum D, Emmerling J, Bertram C, Gernaat DE, Krey V et al (2018) Limited emission reductions from fuel subsidy removal except in energy-exporting regions. Nature 554(7691):229–233

Jiménez E, Tapiador FJ, Sáez-Martínez FJ (2015) Atmospheric pollutants in a changing environment: key issues in reactivity and monitoring, global warming, and health. Environ Sci Pollut Res 22:4789–4792. https://doi.org/10.1007/s11356-014-3850-3

Kampa M, Castanas E (2008) Human health effects of air pollution. Environ Pollut 151(2):362–367

Krug EC, Frink CR (1983) Acid rain on acid soil: a new perspective. Science 221(4610):520–525

Lave LB, Seskin E (1973) Air pollution and human health. Read Biol Man 169:294

Lelieveld J, Evans JS, Fnais M, Giannadaki D, Pozzer A (2015) The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature 525(7569):367–371

Lelieveld J, Pozzer A, Pöschl U, Fnais M, Haines A, Münzel T (2020) Loss of life expectancy from air pollution compared to other risk factors: a worldwide perspective. Cardiovasc Res 116:1910–1917

Likens GE, Bormann FH (1974) Acid rain: a serious regional environmental problem. Science 184(4142):1176–1179

Likens GE, Wright RF, Galloway JN, Butler TJ (1979) Acid rain. Sci Am 241(4):43–51

Luoma JR (1982) The human cost of acid rain. Audubon 90(6):16–23

Muller NZ, Mendelsohn R (2007) Measuring the damages of air pollution in the United States. J Environ Econ Manag 54(1):1–14

Nyambuu U, Semmler W (2020) Climate change and the transition to a low carbon economy–carbon targets and the carbon budget. Econ Model 84:367–376

OECD (Organisation for Economic Co-operation and Development) (2008) OECD Environmental Outlook to 2030. OECD, Paris http://www.oecd.org/dataoecd/29/33/40200582.pdf
Ostro BD (1994) Estimating the health effects of air pollutants: a method with an application to Jakarta, Fuel and Energy Abstracts. 36(5): 370–0. https://doi.org/10.1016/0140-6701(95)97038-L
Ostro B (2004) Outdoor air pollution: assessing the environmental burden of disease at national and local levels. In: WHO environmental burden of disease series, no. 5. World Health Organization, Geneva. https://apps.who.int/iris/bitstream/handle/10665/42909/9241591463.pdf
Pak-EPA, National Environmental Quality Standards for Ambient Air (2010) http://www.environment.gov.pk/images/rules/SRO2010NEQSAirWaterNoise.pdf
Pope CA, Burnett RT, Krewski D, Jerrett M, Shi Y, Calle EE, Thun MJ (2009) Cardiovascular mortality and exposure to airborne fine particulate matter and cigarette smoke: shape of the exposure-response relationship. Circulation 120(11):941–948
Pope CA III, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, Thurston GD (2002) Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Jama 287(9):1132–1141
Record FA, Bubenick DV, Kindya RJ (1982) Acid rain information book. Acid rain information book. Noyes Data Corporation, Park Ridge, New Jersey. https://www.cabdirect.org/cabdirect/abstract/19831975322
Saidi K, Hammami S (2015) The impact of CO_2 emissions and economic growth on energy consumption in 58 countries. Energy Rep 1:62–70
Samimi A, Zarinabadi S (2012) Reduction of greenhouse gases emission and effect on environment. J Am Sci 8(8):1011–1015
Sanchez-Triana E, Enriquez S, Afzal J, Nakagawa A, Khan AS (2014) Cleaning Pakistan's air: policy options to address the cost of outdoor air pollution. World Bank. https://doi.org/10.1596/978-1-4648-0235-5
Schikowski T, Hüls A (2020) Air pollution and skin aging. Curr Environ Health Rep 7:58–64. https://doi.org/10.1007/s40572-020-00262-9
Seaton A, Godden D, MacNee W, Donaldson K (1995) Particulate air pollution and acute health effects. Lancet 345(8943):176–178
Shahbaz M, Lean HH, Shabbir MS (2012a) Environmental Kuznets curve hypothesis in Pakistan: cointegration and granger causality. Renew Sust Energ Rev 16(5):2947–2953
Shahbaz M, Zeshan M, Afza T (2012b) Is energy consumption effective to spur economic growth in Pakistan? New evidence from bounds test to level relationships and granger causality tests. Econ Model 29(6):2310–2319
Sher E (1998) Handbook of air pollution from internal combustion engines: pollutant formation and control. In: Principles of inhalation injuries. Academic Press, Cambridge, pp 58–62
Trasande L, Thurston GD (2005) The role of air pollution in asthma and other pediatric morbidities. J Allergy Clin Immunol 115(4):689–699
U. S. Energy Information Administration (2020) Pounds of CO_2 emitted per million British thermal units (Btu) of energy for various fuels. https://www.eia.gov/tools/faqs/faq.php?id=73&t=11
US-EPA (2020) Benefits Mapping and Analysis Program (BenMAP), BenMAP-CE Training Materials. South Asia. https://www.epa.gov/benmap/benmap-ce-training-materials
Van Dingenen R, Dentener FJ, Raes F, Krol MC, Emberson L, Cofala J (2009) The global impact of ozone on agricultural crop yields under current and future air quality legislation. Atmos Environ 43(3):604–618
Wahid A (2006) Influence of atmospheric pollutants on agriculture in developing countries: a case study with three new wheat varieties in Pakistan. Sci Total Environ 371(1–3):304–313
Weidema BP (2009) Using the budget constraint to monetarise impact assessment results. Ecol Econ 68(6):1591–1598
World Bank (2006) Pakistan strategic country environmental assessment. The World Bank, South AsiaEnvironment and Social Development Unit, Washington D.C
World Health Organization (2006) Air quality guidelines: global update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide. World Health Organization, Geneva
World Health Organization (2009) Violence and injury prevention and disability (VIP). Road traffic injuries, 10. http://www.who.int/violence_injury_prevention/road_safety_status/country_profiles/pakistan.pdf
Zhao D, Sun B (1986) Air pollution and acid rain in China. Ambio 15(1): 2–4
Zweig R (1982) Hydrogen-prime candidate for solving air pollution problems. In: Hydrogen energy progress IV, vol 4. Pergamon Press, New York, pp 1789–1805

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