fire

Review

Combustion and Stubble Burning: A Major Concern for the Environment and Human Health

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Abstract: Combustion is an essential process for humanity, but it has created turbulence in society due to the pollutant emissions from the partial completion of its process and its byproducts. The regular population is unaware of the repercussions being faced in terms of health deterioration, product quality degradation, biodiversity loss, and environmental harm. Although strategic planning against the effects is being applied sideways by the authorities to the local population and industrial facilities, the awareness in the local population is still minimal. The indicators for bioremediation being required, observed through increased sales of pharmaceutical medicines and supplements, air filters, and new techniques, include smog, elevation in respiratory disease, health immune system deterioration, decreasing life span, increasing mortality rate, and degradation in the food and water quality. This article gives a brief overview of the problems being faced due to uncontrolled combustion activities, the sources of pollutants, their creation, emission, and dispersal process, along with the mitigation techniques developed to overcome the after-effects on human health and environment.

Keywords: combustion; fuel; emission; mitigation; human health; environment

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1. Introduction

The exothermic fuel combustion reactions have been regarded as the key reason for air pollution and worsening human health conditions [1]. Their consumption for global energy generation has increased 22-fold, from 5973 tWh in 1900 to 136,018 tWh [2], with the majority being produced via gas-based combustion, followed by coal and oil combustion. The USA, Russia, China, and India are among the foremost fuel-consuming countries. With an 8 million (M) annual death rate due to fossil fuel pollution (2018), s 3.2 M yearly death rate, and 237,000 infant fatalities due to household emissions (2020), the emissions from industries (e.g., iron, steel, aluminum, and coke production), household (e.g., cooking and indoor heating), traffic and roadway (vehicular exhaust from gasoline and diesel consumption), and coal, petroleum, and vegetative fuel combustion, often produce several byproducts from complete and incomplete combustion process which are being classified as a threat to human health and environment [3]. Stubble burning is a common agricultural practice that can have significant environmental air pollution concerns and impacts on human health. Conversely, the burning of chaff produces large amounts of particulate matter and causes serious respiratory impacts [4]. An increasing population leads to increases in crop production demand, thereby increasing stubble production. The effect of crop residue burning in northwest India can be directly evaluated with a study stating

149 million tonnes (Mt) of carbon dioxide (CO_2), 9.0 Mt of carbon monoxide (CO), 0.25 Mt of sulfur oxide ($SO_{X)}$, 1.28 Mt of particulate matter (PM), and 0.07 Mt of black carbon (BC), which has found to be directly affecting Delhi's air quality index (AQI) [5]. Smog increase had led to 84.5% of the population suffering from heart disease, 76.8% from eye irritation, 44.8% from nose irritation, and 45.5% from throat irritation. Cough increased by 41.6% and wheezing problems by 18.0% [6]. In the Delhi National Capital Region (NCR), an amount of 1.35 Mt of crop residue burning is to expected by the end of 2023 [7]. The oxides of carbon (C), nitrogen (N), and sulfur (S), polycyclic aromatic hydrocarbons (PAHs), aromatic amines, heterocyclic aromatic compounds, formaldehyde, volatile organic compounds (VOCs), benzene, aldehydes and alkenes, soot, and other fine particles are byproducts of combustion. The pollutants released may enter the environment as additional constituents, unbalancing the stabilized greenhouse gasses' (GHGs)—i.e., CO_2 and methane (CH_4)—concentration in the atmosphere, which keeps the heat energy from escaping into space, resulting in global warming. According to the system of air quality and weather forecasting and research (SAFAR), stubble burning's contribution to air pollution (as PM) was 25% in 2021, 32% in 2020, and 19% in 2019, while the fire count between September and November was 71,304 in 2021, and 83,002 in 2020, respectively. This has been known to directly affect Delhi's AQI [8]. The mitigation of GHGs is feasible by various biological approaches towards value-added products [9–11]. The Indian Agency for Research on Cancer has classified outdoor air pollutants under the human carcinogen category, as they have turned earth's air unbreathable [12]. The un-stabilized atmosphere gas concentration has become an instigating factor of human health, resulting in cardiovascular (ischemic heart disease), respiratory (acute lower respiratory tract infection, chronic obstructive pulmonary disease, asthma, lung cancer, tuberculosis), and genetic diseases (heart attack, asthma, coughing), as well as cancer and premature death [13–15]. Thus, the repercussions faced by mankind and the environment due to combustion activities and stubble burning have been briefly discussed in the article, along with their sources and some mitigation strategies for creating awareness about combustion activity-based pollution and its status in society.

This review is a collection of theoretical, modeling, and experimental studies from 2015 onwards evaluated with the help of PubMed, Google scholar, Science direct, and Research gate search tools. A narrative review provides an overview of issues associated with uncontrolled combustion activities and pollutant sources along with mitigation techniques for sustainable human and environmental development.

2. Combustion and Stubble Burning Effluent Emissions

The planet has supported the production of ample oxygen and combustion fires since the time of adequate vegetation. Fire regimes are highly influenced by ecosystem composition, viz., fire frequency, spatial continuity, size, seasonality, types of fire (surface or ground fire, crown fire), fire severity, and intensity [16,17]. Industrial combustion, domestic combustion, societal combustion, agricultural combustion, and support services are the significant influencers of combustion due to human involvement with some risks and benefits [18]. The most tenacious combustion occurrence is smoldering combustion, as it is the most destructive fire process, which is a slow and low-temperature activity and a flameless burning process. Smoldering combustion is emerging as an industrial and environmental challenge; smoldering fires are a rising concern globally. During the smoldering process, sometimes, the flames' disappearance follows a greater extension, devouring amounts of fuel and liberating toxic gases in the environment. Sturdy buoyant forces are involved in these kinds of fires, where firebrands initiated by bark and twigs are elevated and carried long distances (hundreds of meters) by the wind in downward directions, igniting several fire scenes [19]. There are research gaps in smoldering combustion, which can also be a beneficiary process for human beings. To have detailed knowledge, one can make use of recent reviews [20–24]. Globally 26–29% of forest loss is because of forest fires during the 2001–2019 period, which is higher compared to the 2001–2015 (21–25%) and 2003–2014 (12–18%) periods. Due to fire incidents, boreal forests have a high segment of forest loss (69–73%), following subtropical (19–22%), temperate (17–21%), tropical (6–9%), and rainforests (7–9%). Australia has an increasing trend in forest loss in the tropical, subtropical, and temperate areas, and in Eurasia, boreal forests demonstrate a high loss proportion [25–27]. In India, about 52,785 and 345,989 forest fires were analyzed from Nov 2020 to June 2021, i.e., the forest fire period, using a moderate resolution imaging spectroradiometer sensor and Suomi National Polar Orbiting Partnership Visible Infrared Imaging Radiometer suite. In Indian forests throughout the fire season, 54.4% see occasional fire, with 7.49% moderately frequent fires and 2.40% high incidence levels, and 35.71% remains non-exposed [28]. Recent fire events in Brazil, Australia, and California have again drawn full attention towards forest fires, chiefly the Amazonian fires, where whether forests or deforested areas were burning was not clear [29,30]. On the other hand, the waste and recycling industry is on the verge of providing energy, recycling, sorting, and yielding waste fires, which is an epidemic, as reviewed by Fogelman (2018). Germany, the UK, Sweden, Austria, and Italy are some of the major countries in Europe with the most incidents of waste fires [31,32]. However, major health risks were also observed with the waste fire incidents that have occurred in the cities of the USA and Thailand [33,34]. Stubble burning is the major contributor of air pollution by emissions of CH_4 SO_x, PM of 10 (PM_{10}) and 2.5 ($PM_{2.5}$) microns, nitrogen oxides (NO_x), CO_2, and CO in mostly South Asian countries such as India, Nepal, Bangladesh, and Pakistan and also in China (Figure 1). Globally, around one-fourth of biomass burning activities (household cooking, countryside communal refuse ignition, wildfires) are constituted by stubble burning regimes including forest fires comprehensively [35]. Due to changes in patterns of cropping and harvesting and water scarcity, agricultural fires are increasing in India [36]. Despite various interventions and the banning of these crop residue burning practices, this burning regime is still extensive. It has engendered about 44,000–98,000 deaths in 2003–2019, with the exposure of PM substances in the atmosphere where Haryana, Punjab, and Uttar Pradesh are the major contributors (Figure 2). India has a rich diversity of crops including rice, wheat, coarse cereals, pulses, oil seeds, sugarcane, cotton, jute and mesta, but rice and wheat, being rich producers, have a more diversified impact as their residues are burnt in large amounts for cropping processes. Sugarcane's residues are also burnt in large amounts in India. About 6600 Mt of these crops residue were burnt during 2003–2016 [37]. There is a literature gap in studies of stubble burning and Diwali fireworks as these two events coincide with each other in India. Thus, the effect of the festival fireworks is somehow the same; stubble burning as SO_2 and $PM_{2.5}$ (900 $\mu g/m^3$) are the major pollutants emitted during the fireworks process [38]. Combustion effluents are generated in response to the behavior of the burning process and product toxicity, which further resides in the fire plot (orientation and fuel's shape), material composition, oxygen concentration, and temperature. These combustion effluents are gases, vapors, and liquids, and solid particles mix in varying ratios of combustion conditions to the material's organic and elemental composition [39]. The effluents produced in the environment after burning the products are irritable and asphyxiant to humans. Asphyxiate gases, irritable gases, and complex molecules are some significant types of combustion effluents (Figure 3).

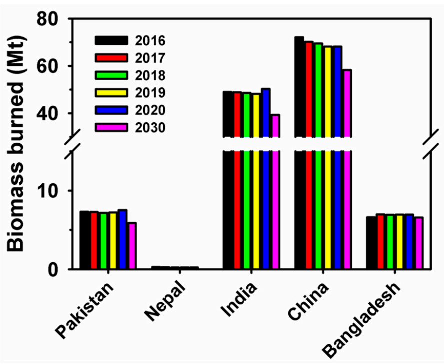

Figure 1. Statistics depicting the biomass burned of all crops in tonnes from the year 2016–2030.

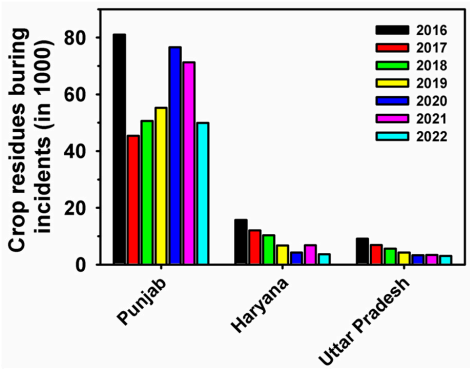

Figure 2. Major states of India following stubble burning practices.

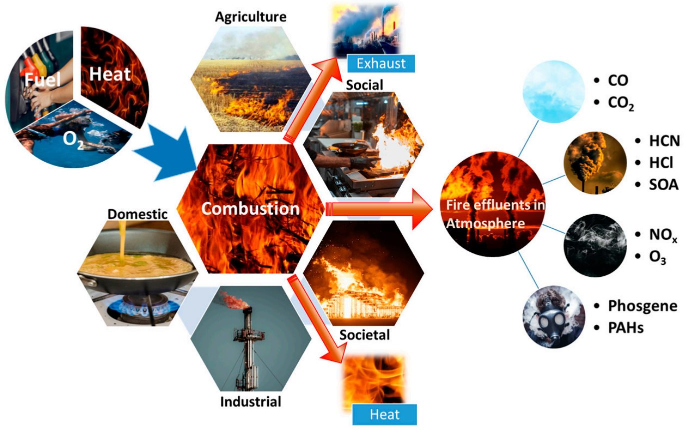

Figure 3. Reaction for combustion exhibiting effluents in the environment and different types of combustion (CO (Carbon monoxide), CO_2 (Carbon-dioxide), HCN (Hydrogen cyanide), HCl (Hydrogen chloride), Secondary organic aerosol (SOA), NO_X (Oxides of nitrogen), O_3 (Ozone) and PAHs (Polycyclic aromatic hydrocarbons)).

2.1. Combustion and Stubble Burning Contribution

Combustion, on the one hand, is full of risks and, on the other hand, is equally responsible for a number of benefits. The combustion process involves generating energy, heat, light, chemical species, mechanical work, and plasma. During the reaction between diesel fuel, hydrocarbons, oxygen, carbon dioxide, and water are produced, resulting in combustion. This conversion of diesel fuel to energy is obligatory for power buses; further, it also helps in exhausting the greenhouse gases responsible for climatic change and toxic air pollutants which smudge the atmosphere [40]. A total of 25% of the world's power is provided by internal combustion engines (ICE), which are operated by fossil fuel oils. ICEs are enhanced by the conversion of catalysis beneficial to uniting emission standards with a coating of a metal catalyst to ceramic structure in order to reduce pollutants and intensify combustion. ICEs are still the transportation industry's future, so there should be future efforts to reduce greenhouse gas emissions in the environment, which will be discussed in the coming sections [41]. Hydrogen-fueled (HF) ICE (HF-ICE) can be a potent approach for ecological road mobility elucidations, which will also meet the neutrality objective of the EU's 2050 CO_2. These HF-ICE are advantageous over diesel engines in automobile industries as they have virtually no emissions and lofty efficiency. So, HF-ICE should be taken into consideration, noting both its advantages and its limitations [42]. Rice husk combustion (1 tonne/h) can boost an average net of 600–700 KWh electricity for any power plant with less NOx and CO effluent emission (below 250 ppm). Moreover, rice husk ash can recover bio-silica of 99.7% purity. So, rice husk combustion can be utilized for energy development [43]. Coal is the ally of the world for electricity production compared to other sources, producing 40% of the world's supply. Abundance, affordability, standard technology, reliability, efficiency, and safety are the key benefits of coal-fired power plants [44]. The year 2021 has seen increased energy generation by coal-fired power plants by 8%, which has technically reversed the decline over the past two years. European Union (20%) > United States (16%) > India (13%) is the increasing demand trend for coal-fired stations [45].

Incorporating agricultural stalks (decomposition) into the soil can increase its fertility and level of nutrients, organic matter, microbial activity, and water-holding capacity. Bio-decomposition and vermicomposting are some of the decomposition techniques for crop residue management that are helpful in the generation of bio-compost and bio-fertilizers, respectively, which can be further used in agricultural practices. Biochar production by the conversion of biomass by thermal combustion can be used for reducing carbon footprints during rice production [46]. Crop residue waste can be used to produce biogas, bio-hydrogen, and bioethanol; 12 TWh of electricity can be generated in biomass power plants with crop residue usage [47]. In Iran, a study evaluated that 2082 Mm^3 (hydrogen), 6542 Mm^3 (biogas), and 2443 M liter (butanol) could be yielded by 24.3 Mt of crop residue [48]. Crop residues can be used for bioenergy production and thus will be helpful for waste and air pollution management.

2.2. Dispersal of the Combustion and Stubble Burning Effluents

During the combustion of various materials, many effluents are dispersed in the environment, which can have an affect depending on the exposure duration, receptor susceptibility, and transmission process. These combustion effluents consist of solid gases, vapors, and liquid droplets with a particular size range. After cooling fire effluents, a chemical composition still exists where vapors form in submicron fields by condensation into liquid droplets and solid particles. Inhalation hazards during a fire by the occupants in remote areas are prevented when acid gases, organic particulates, and vapors are retained on building surfaces and elevated after fire risks [49]. The effluents are emitted into the air, water, and terrestrial environments. PAHs, hydrocarbons, VOCs, metals, dioxins, suspended solids, and ammonia are key concerning effluents produced during the firing process [50]. Burning stubble, such as sugarcane, can accumulate mercury in the soil and streams. Mercury can be toxic to humans and wildlife and cause developmental problems in fetuses. Stubble burning is the source of major gaseous pollutants, i.e., GHGS, NOx, SOx, and PM (PM_{10} and $PM_{2.5}$), causing major human and environmental health issues. Approximately 63 Mt of crop stubble can emit CO (3.4 Mt), CO_2 (91 Mt), CH_4 (0.6 Mt), NOx (0.1 Mt), and PM (1.2 Mt) into the environment [4]. A recent study likely reported CO_2 (176 teragrams (Tg)), CO (10 Tg), CH_4 (314 gigagrams (Gg)), N_2O (8.1 Gg), NH_3 (151 Gg), non-methane volatile organic compounds (NMVOC, 814 Gg), $PM_{2.5}$ (453 Gg), and PM_{10} (936 Gg) emissions from crop residue burning in northwestern India [51]. These stubble burning pollutants are transported from the Indian Punjab region to Pakistan, and vice versa. According to the air's trajectory analysis, it was found that with compact bumps from the adjacent countries, transnational dispersal of pollutants exists across Bangladesh, India, Pakistan, and Nepal [52,53]. According to the world bank data, USD 8.1 trillion yearly is the cost of health damages originating by air pollution, which corresponds to 6.1% of the gross domestic product (GDP) globally [54]. In India, USD 28·8 billion of economic losses were recorded in 2019, and this cumulative deprivation of USD 36·8 billion was 1.36% of India's GDP [55].

3. Health Concerns and Impact on the Environment

The impact of emission constituents on the environment and human health is assessed with respect to the fuel type, emissions, ambient concentration, exposure time, dose amount, and population type (location, age, sex, immunity, physical health, sensitive group, and additional health conditions). This has been observed in children, who have a high a comparatively vulnerability rate, in the research mentioned by Perera and his coworkers and Calderón and his coworkers on the differential impact of air pollutant exposure on the younger generation from different economic categories, skin pigmentation, and geographical location [56,57]. The exposure to the fuel emissions released results in the entry of these pollutants into the respiratory tract, distal organs, tissues, and bloodstream causing viral infections, neurodevelopmental disorders, allergic reactions, depleting immunity response time, and genetic alterations, as experimentally proven in epidemiological studies [58–60].

3.1. Environment Impact on Biotic and Abiotic Factors of the Ecosystem

The pollutant exposure of the human population, especially of the sensitive age group, to air with poor AQI entering the internal system overturns the body's biochemical processes and physiology. This underlies the occurrence of neurodegenerative disorders, cardiometabolic, cognitive impairment, Alzheimer's, and Parkinson's disease, structural change in the respiratory tract, airway pathway and alveoli oxidative stress, inflammation, disturbing levels of IgG antibodies, bisphenol A and cerebrospinal fluid DNA damage (e.g., methylation), epigenetic instability, telomere attrition, mitochondrial injury, abnormal protein homeostasis in key progenitor and structural cells, decrement in regenerative power and immune response, pulmonary fibrosis with many other degenerative harmful effects [61,62]. This has also been reported in the age group of 4–12 years, who were exposed to emission pollutants (combustion metals, $PM_{2.5}$, ultrafine particles, Ozone, formaldehyde, and Ni, with additional TAR DNA-binding protein pathologies observed in megacity children (Mexico)). Other than epidemiological experimentation, in recent research studies, the impact has been estimated using a model-based evaluation which is now being used to analyze combustion initiation (substrates, reactants, and products), spread (interaction with environmental factors and biological systems), and impact process (overall effect on the living and the abiotic), followed by the application of mitigation strategies and the after-effects of these solutions.

The straw burning increases $PM_{2.5}$ by 10 $\mu g/m^3$, causing a mortality rate hike of 3.25% (1.56% per month), contributed mainly to a rise in cardiorespiratory cases by 1.82% [63]. A 10-point increment in the amount of straw burning might lead to a 1.71% rise in all-cause mortality rates and 1.91% rise in cardiorespiratory mortality rates. Another similar study where fixed-effects panel regression models in combination with high-resolution satellites for monitoring 1650 ground-level stations (2013–2015) during straw burning observed 2096 (2013), 1861 (2014), and 2038 (2015) in three years from 2013–2015 in 157 cities' burning points and pointed out the direct effect of straw burning on PM concentration (92 $\mu g/m^3$ per month observed). A 10-point monthly increase in burning incidents leads to a 3.67% increase in urban PM_{10} by a value of 5.19 $\mu g/m^3$ [64]. The moderate resolution imaging spectroradiometer (MODIS) satellite images and ground-based monitoring pointed out the proportionality between the rice straw open burning and the ambient air quality in Pathumthani (Bangkok Metropolitan Region) through the high number of hotspots observed in the burning season (November 2003–April 2004). A linear relationship of the number of total hotspots with R^2 of 0.56 for CO and 0.77 for PM_{10} was observed, resulting in high air pollution levels in the area [65]. According to model-based research by Lan and coworkers using Global Fire Emission Database v4.1s with Regional chemistry and transport model (2003–2019), 64–90% of residue emissions from Punjab, Haryana, and Uttar Pradesh crop is the contributing reason for observed premature deaths (40,000–100,000), with respect to the Integrated Exposure Response Function and the India Specific Value of Statistical Life [37]. There is a differential impact of air pollutant exposure on the younger generation from different economic categories, skin pigmentation, and geographical locations observed. Thus, combustion pollution affects populations with various characteristics. The impact on vegetation includes decreased activity of photosynthetic machinery, the water transport system, the nutrient uptake and assimilation system, reduction in plant growth, seedling weight, biomass, and nutrient content, chlorosis, necrosis, high metal accumulation in plant parts, and wilting, which has also been validated by the different model system [66–68]. Soil fertility, water holding capacity, nutrient content, and microbiota become affected as the contaminants from emissions settle on soil [69,70]. Fuel emissions, when in contact with the earth's atmosphere, increase the temperature levels and breathing air concentration variability (due to escalated concentration of greenhouse gases in the atmosphere), causing infiltration of more UV rays, rises in sea level, ocean acidification, acid rain, degraded visibility due to heavy smog (smoke and fog), microbiota variability in air, water, and soil due to variance in biogeochemical cycles. The direct and prolonged effects have been reported by different research studies [71–74], During the combustion of various materials, many effluents are dispersed in the environment which have an impact depending on the exposure duration, receptor susceptibility, transmission process.

3.2. Reaction Processes between Effluents and Environment

The combustion process, on its forthcoming release of pollutants in the atmosphere, allows the pollutant to interact with the existent abiotic factors. The biogeochemical cycles are affected directly, as the pollutant gas concentration in the atmosphere is elevated from the normal limited concentration level, altering the substrates and products involved in the continuous processing cycle. As a result, the end product of the cycle interacting with a definitive source such as air, soil, and water alters the course [75]. CO_X released in the atmosphere as exhaust gas results in temperature elevation of the earth as a greenhouse gas by absorption and heat radiation energy (greenhouse effect). Fly ash, when released with the oxides of sulfur and nitrogen, affects the cloud condensation and ice nucleation activity-assisted fly ash. As for NO_X and $SO_{X,}$ as they rise in the air after releasing as emission, their oxidation occurs in the presence of O_2 (air) and H_2O (rainwater), resulting in acid rain [76]. VOCs, other than increasing the Earth's temperature (greenhouse effect), damage the material surface and causes tropospheric photochemical oxidant formation, ozone layer depletion, release of odor, the formation of smog (VOCs in smoke combine with fog) [77]. The common pollutants such as CO_2, CO, CH_4, N_2O, NOx, SO_2, black carbon, non-methyl hydrocarbons (NMHC), VOC, and PM released from stubble burning have a direct impact on the environment and health. Air pollution's effect on animals, vegetation, and other organisms in the surrounding niche has been observed to be detrimental [78]. The paddy residue burning cost is INR 8953 per ha, with INR 31,990 M annual social cost in the region of northwest India, with 1 tonne accounting for 5.5 kg of N, 2.3 kg of phosphorous (P), 25 kg of potassium (K), and 1.2 kg of S [79]. Along with a nutrients loss of 100% of C, 80% of N, 25% of P, 21% of K, and 50–60% of S in soil, a release of 3 kg of PM, 60 kg of CO, 1460 kg of CO_2, 199 kg of ash, and 2 kg of SO_2 from 1 tonne of straw burning was also observed [80]. The effect of burning different crop residues on the environment and health has been briefly described in Table 1.

Table 1. Impact of most commonly produced crops burning on pollution generation, environment, and health.

Crop	Crop Residues	Residue Produced per Year	Pollutant Concentration Generated from Burning	Effect on Human Health	Effect on Vegetation/Soil	References
Rice	Husk, bran	170 Mt	5.34 M of CO_2, 0.04 Mt of CH_4, 0.42 of CO, 2000 tonnes of NO_X, 2000 tonnes of SO_2, 0.04 Mt of $PM_{2.5}$, 0.04 Mt of PM_{10}, 2000 tonnes of BC, and 14,000 tonnes of organic carbon from 4.54 Mt residue burning	A pulmonary disease resembling asbestosis, namely pleural fibrosis and possibly bronchogenic carcinoma, and acute bronchitis	Soil nutrient loss (1995–2009, India): N of 0.24 Mt per year, P of 0.01 Mt per year, and K of 0.2 Mt per year	[81–83]
Wheat	Bran, straw	110 Mt	6185 tonnes of PM, 35,983 tonnes of CO, and 1125 tonnes of CH_4 considering a head fire burning or 3373 tonnes of PM, 30,360 tonnes of CO, and 731 tonnes of CH_4 by backfire burning were estimated from 6.2 tonnes of wheat straw	Chronic obstructive pulmonary disease, pneumoconiosis, pulmonary tuberculosis, bronchitis, cataract, corneal opacity, and blindness	Soil nutrient loss (1995–2009, India): N of 0.08 Mt per year, P of 0.004 Mt per year, and K of 0.06 Mt per year	[4,83–85]

Table 1. *Cont.*

Crop	Crop Residues	Residue Produced per Year	Pollutant Concentration Generated from Burning	Effect on Human Health	Effect on Vegetation/Soil	References
Sugarcane	Tops, bagasse, molasses	12 Mt	CO of 929 Gg, CO_2 of 8864 Gg, and $PM_{2.5}$ of 152 Gg from 1007 g_{dm} per m^2 sugarcane residual biomass	Increases of 10.2 µg/m^3 in $PM_{2.5}$ and 42.9 µg/m^3 in PM_{10} were associated with increases of 21.4% [95% confidence interval (CI), 4.3–38.5] and 31.0% (95% CI, 1.25–60.21) in child and elderly respiratory hospital admissions, respectively	Soil nutrient loss (1995–2009, India): N of 0.08 Mt per year, P of 0.001 Mt per year, and K of 0.03 Mt per year	[83,86,87]
Cotton	Linter, staple, stalks	53 Mt	57 ppm CO, 196 NO_X, H_2S 37 ppm, CO_2 7.92%, 12.81% O_2 for cotton stalks	Respiratory system disorders, and cardiovascular mortality	N of 0.2 kg, P of 0.8 kg, K of 6.1 kg, and S of 1.5 kg	[85,86,88,89]

4. Aftermath of Combustion and Stubble Burning

Combustion and stubble burning come with self-declaring productive and fatalistic effects in excessive amounts with short- and long-term impacts in regional, urban, and environmental areas, globally. Smoldering and flaming fires have diverse effects: peat land wildfires produce haze-like pollution episodes affecting various people's health and suppression difficulty. The main cause of wildfire mortality is the prolonged duration of the substantial transfer of heat during smoldering to the forest surface. These sunken fires release primeval carbon hoarded in the soil, which has matured for more than 10,000 years [90]. It is very critical to ensure the prevention and dominance of fires in coal mines, which increase future coal fire risks, coal-dust pollution, property losses, damage to equipment, and gas accidents [91]. Air pollutants are produced through combustion by which the land carbon cycle is influenced further, resulting in damaged photosynthetic vegetation and affecting photosynthetic processes with the increase in diffuse radiation, thus diminishing terrestrial productivity [92]. Between 15–25 years, areas burning below the prescribed fire conditions succeeding large-scale mortality become converted to long-term shrub fields due to the significant loss of seed sources and regenerative trees for the regeneration of post-fire conifers [93]. Fires have negative and positive ecological impacts, namely, global warming, land infertility, damaged ecological diversity, nutrient recycling, and vegetation regeneration (Figure 4) [94].

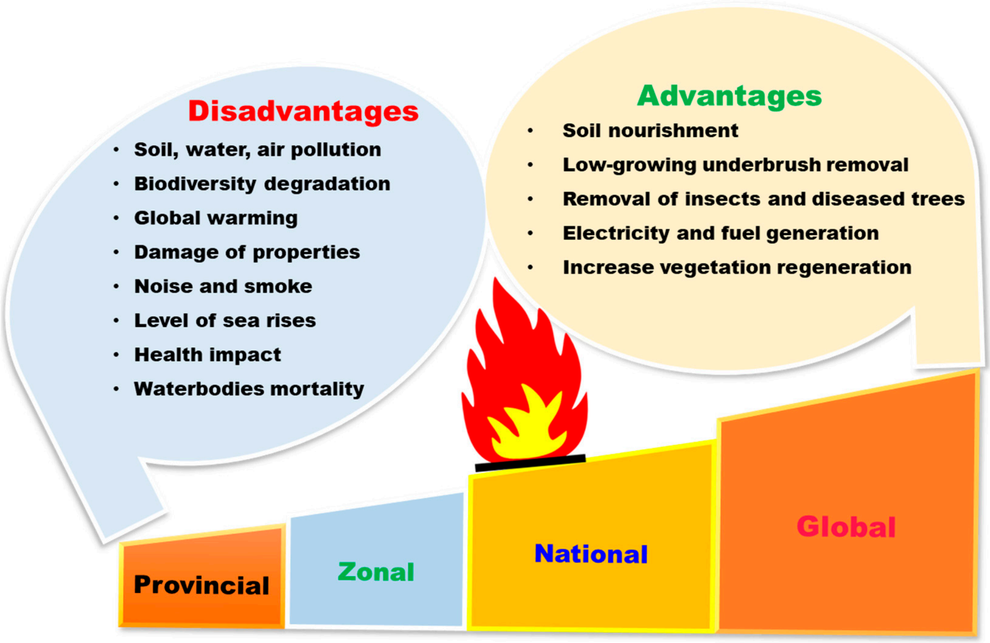

Figure 4. Advantages and disadvantages of combustion in all regions globally.

5. Combating Alternatives and Strategies

Recently, a report has been analyzed by the International Association of Fire and Rescue Services (CTIF) in which detailed information has been recorded for all the fire incidents which occurred globally from the year 1993 to 2020 [95]. In the present review, we have presented relative data for the fire occurrences throughout the years from 2016 to 2020 in various countries, chiefly, the USA, China, India, Russia, and Spain, and Republic of Korea (Figure 5), as these are the major countries for fuel and energy production. The fire outbreak scenario is 1388,500 (2021) > 454,206 (2020) > 345,989 (2021) > 252,000 (2020) > 129,544 (2019) > 38,659 (2020) for the USA, Russia, India, China, Spain, and Republic of Korea, respectively. Different types of fire were reported as follows: USA: 15% vehicles fire, 19.9% grass/brush fire, 16.2% rubbish, 13.4% others; Russia: 3.8% vehicles fire, 3.3% forest fire, 28.1% grass/brush fire, 26.9% rubbish, 5.2% others; Republic of Korea: 11.8% vehicles fire, 2.0% forest fire, 2.2% grass/brush fire, 7.6% rubbish, 11.9% others. The number of fire deaths were also analyzed in these countries based on year, inhabitants, and fire number, as summarized in (Table 2). In 2020, it is examined that around 24.2% of fires occurred in residential buildings and other fires were basically limited to forest, grass, and rubbish areas. In these fires, 61% are burn injuries and 82.5% of fire deaths have been registered.

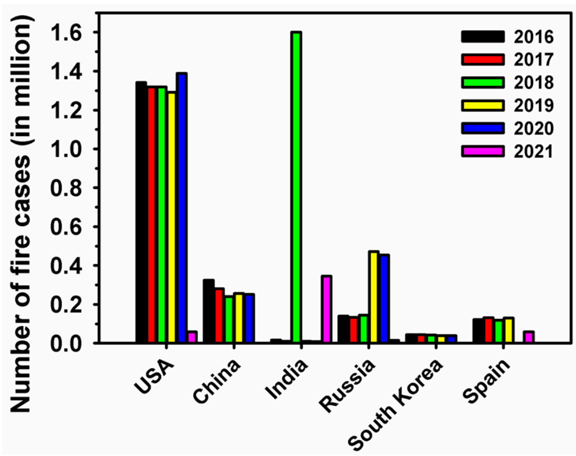

Figure 5. Fire outbreak statistics from 2016 to 2021.

Table 2. Mortality numbers recorded in year 2020.

Country	Average No. of Deaths per Year	Average No. of Deaths per 100,000 Inhabitants	Average No. of Deaths per 100 Fires
China	1183	0.09	0.47
India	13,429	0.99	0.84
USA	3530	1.06	0.27
Russia	8270	5.63	3.08
Republic of Korea	329	0.63	0.79
Spain	169	0.36	0.13

The effective counter strategies include reducing the dependency on combustion, improving combustion efficiency, using clean technologies, controlling the combustion process for lesser emissions, recycling emission pollutants, and reducing the health impact by combating measures concerning economy control [94]. The air pollution control methods usually applied are the use of scrubbers, air filters, cyclones, electrostatic precipitators, mist collectors, incinerators, catalytic reactors, biofilters, powertrain technologies (hybridization, diagnostics, and controls), fuel emulsifiers, additives, blenders, injection strategies, Sand WFGD technologies [96,97]. Other pollutant reduction methods, including air and fuel staging, flue gas recirculation, selective catalytic reaction systems, low-pressure exhaust gas recirculation (diesel engine), and automatic identification system-based ship traffic exhaust emission systems, have also been reported for their efficient application [98–100]. The existing and new fuel process and emission assessing technologies require a thorough study for their path layout, application design, and the curbing of negative results and limitations. The integration of mathematics and artificial intelligence as a combating strategy has been found to be quite efficient. Several emission prediction model systems help in finding out the total emissions and mitigation applications, such as ANFIS-PSO (Hg), SARFIMA-NARX, CALPUFF, AERMOD (marine), and GEOS-Chem (version 9.1.3) [101,102]. Following the initiatives and energy policies taken by China under the Air Pollution Prevention and Control Action Plan (APPCAP), WRF-CMAQ ($PM_{2.5}$) was created to control $PM_{2.5}$ [103,104]. The provincial emission reduction policies and provincial renewable energy policies have been found to have positive impacts on the reduction of PM10 and SO_2 and $PM_{2.5}$, respectively [105]. Moreover, several states have created policies, applied strategies, and assessed their limitations against combustion-based pollution and have already received better results alongside working on the critical failures. The goals are set out by the United Nations sustainable development goals (UN-SDGs). Goal 13 aims for climate preservation by taking control over pollution emitting means. It is followed by UN-SDG-7, which is looking for sustainable solutions to replace the process, since most of the anthropogenic activities have become a necessity for the continuation of socioeconomic [106]. Several countries, namely, the USA and India, have created policies and laws such as emission reduction and renewable energy policies to keep the industries under control, such as the Clean Air Act, the National Biofuel Policy of India, the Global Burden of Disease–Pollution and Health Initiative [107–110]. In India, with the use of in situ (CRM machinery, PUSA bio-decomposer) and ex situ crop residue management, the paddy crop stubble burning number has been found to improve with a reduction of 24,758 (31.5%) in 2021–2022. This is due to the introduction of the Crop Residue Management (CRM) Scheme (2018–2023) by the Indian Government with a released fund of INR 30,620 M, which has been utilized by different states for purchasing machinery and custom hiring centers, causing the amount of stubble burning to drop by 3326 (47.6%) in Haryana, 21,382 (30.0%) in Punjab, 50 (19.3%) in Uttar Pradesh, Rajasthan and Delhi (NCT), and a total drop of 56 AQI in Delhi. The total CRM machinery purchase is 1.20 Lakh in Punjab, 72,700 in Haryana, and 7480 in Uttar Pradesh with an included number of 30,975 custom hiring centers in Punjab and Haryana [111]. In situ incorporation, including the use of reaper binder, baler, straw chopper, rotavator, mulching, seed drill, and happy seeder, are a few methods followed as alternative pathways for reusing the crop residue to decrease the amount of residue burning, which overall reduces the impact on the environment [112,113]. Another alternative source for overcoming the impact of residue burning is bioenergy conversion [114]. A study carried out to evaluate this possibility resulted in biochar with 0.985 MJ input/MJ output index and 72.3% energy efficiency, which was the most energy-valuable pyrolysis product. The use of crop residue in pharmaceutics is still undergoing research. Pharmaceutical medicines, such as Unani medicine, are used for countering poor air quality generated health issues [115]. Using similar studies, mitigation techniques can be applied and checked using mathematical models to prove their overall methodological performance and efficient results. This results in less time consumption, limitation removal, and clearance for the developed sustainable combustion process to be applied at the macroscale, globally.

6. Opinion

Many households and large-energy-producing industries use batch-boilers (solid fuel usage), releasing large amounts of harmful compounds in the environment, which also exceeds the standard protocol of PN: EN 303-5:2012. So, these less-efficient heating sources should be replaced with modern or significantly more efficient equipment following standard procedures [116]. Electricity generation should be encouraged using, among other alternative, biogas, a renewable source for waste management produced by carbonaceous residues (biomass) via ecobiotechnological approaches and the co-digestion of feed for their efficient valorization along with value-added products generations [117–122]. This gas can be used as a fuel or can even be ameliorated as bio-methane. As of 2018–2019, India generated about 2.07 billion m^3 of biogas annually. Therefore, biogas can be a potential manager for crop residues that are burned on a yearly basis [123]. Lignocellulosic and algal biomass is a new perspectives on producing green plastics as they emit no pollutants and reduce stubble burning. This bio-based approach can lead to a vast global economy for farmers and advance innovations domestically [124]. As the monoculture farming techniques pollute the environment, new policies should be developed such as crop rotation which is an ecofriendly policy. Still, in exchange, it is also polluting the surroundings due to continuous stubble fires between crop harvests. So, if policies are to be developed, the government should discern and focus on the farmers' necessities, further resulting in positive impacts rather than negative [125]. Likely, the groundwater act was implemented to prevent the shortage of groundwater. Still, in response, this policy led to shrinkage and delays in the harvesting of wheat and paddy with expanded stubble fire regimes. The National Policy for Management of Crop residue (NPMCR) policy has been enforced by the Indian government. A 5% decrease in stubble fire processes in India has been noted to date but still lacking in many ways [126]. Crop residue management practices should be posed not for the time being, and for a single region, but one-for-all strategies should be employed because farmers are trying to adopt the management processes but are unwilling to do so due to financial unavailability and scientific plots such as Pusa decomposer (limited by weather, humidity, and temperature conditions). So, financial commitments should be provided to the farmers to reduce the Parali burning scenarios [46]. The rice straw in in situ management systems can be developed with the help of wheat's direct seeding in the harvested field to increase the soil's efficacy and reduce the costs. The improved seed drills and furrow openers can be helpful for sowing wheat, eliminating air residues (pollutants), and producing higher and potent yields [127]. Green biorefinery can be developed with the use of rice straw waste biomass for the production of valuable products in Asian countries [128]. Pine needle, sewage sludge compost, and olive pruning are some of the major organic wastes with higher elemental value (K, Ca, Mg, Na), which can be used as crop nutrients (biofertilization efficient) [129]. Studies have been undertaken where it has been found that quality fuel can be produced with a mixing of biodiesel and diesel oil, which can result in the reduction of exhaust ejaculations and exhibit superior engine performances. Moreover, in diesel particulate filter burner-type active regeneration methods are the most widely used methods [130]. Corn-cob, the residue of maize crop (high in nutrients), can be a major source of biofuel, heat, and gasification of ethanol over traditional sources, as it is a less resource-demanding crop [131].

7. Future Challenges and Perspectives

Fire plays a crucial role in impacting the ecology of the burning sites. Many approached to improving and diminishing fire effects are still not studied. This section focuses on the future work that should be considered for research. Monitoring fire should be focused on long-term outcomes rather than short-term ones. The predictive, spatial, and temporal scales should be studied for fire's ecological understanding to minimize deprivation and maximize economic, ecological, and cultural gains. Combustion duration period, the content of energy, distribution of size, and number density should be analyzed from the waste-fire firebrand's shower. Firebrands' ignition events, temperature, fluxes, transportation, fire extinction with char layer growth, and potential fire size need to be evaluated. Research should be focused on trench building for firebreak in peat fires and grabbing knowledge to assess the required amounts of water for fire extinguishing. The scale and pace of benefiter fire and mechanical treatments should be increased without relying on pursuing fire suppression. Gel-stabilization foam, like most techniques, should be developed so that in coal burning-like processes, fire body temperature can be reduced with reduced thermal radiation and carbon gas emissions [132]. Coal-based composite fuels and coal-water slurries with and without petrochemicals should be introduced in coal-based power plants for the development of the green power plant industry. Decomposition processes, fodder and feed markets, happy seeder-like advanced machinery, crop diversification, and awareness campaigns should be encouraged for stubble burning mitigation issues.

8. Conclusions

Fuel combustion is a vital process for obtaining energy and carrying out several industrial processes involved in socioeconomic regulation, which are essential and beneficial for the continuation of daily lifestyle. The reality of the pollution and environmental deterioration from fuel combustion process-based outcomes cannot be denied since the combustion process is vital for mankind. Mitigation strategies, model system-based interrogation, accession, evaluation, and validation of applied emission control techniques are the solutions developed for combating the emissions produced, targeting each pollutant differentially since their reactive processes is different. Several research studies, policies, laws, UN-SDGs, and objectives are the limitations that have bound the population into controlling their unregulated anthropogenic activities, which have been causing elevations in pollutant concentration in the environment. This article presents a brief overview of the fuel combustion problem that mankind is facing, and the aggressive strategies being applied at present. The extra input initiatives are still required, and becoming aware of sustainable development and taking individual initiatives seems the only choice.

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