Post-Pandemic Reflections: Long Term Impacts of COVID-19 on Agroecosystem Restoration

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Abstract. The COVID-19 pandemic, initiated in 2020, resulted in significant disruptions to environmental, economic, and social systems. Efforts to restore agroecosystems, essential for reversing land degradation, improving food security, and enhancing climate resilience, were notably affected during this period. This paper reflects on the long-term impacts of the pandemic on agroecosystem restoration initiatives over a five-year period across various contexts. This study examines the impact of lockdowns, labour shortages, supply chain disruptions, and changes in funding priorities on restoration activities, utilizing a synthesis of recent literature, case studies, and field reports. It underscores the development of adaptive strategies, including localized food systems, digital agricultural tools, and community-led restoration, which contributed to resilience during crises. COVID-19 posed significant challenges; however, it also stimulated innovations and policy adjustments that may enhance future restoration initiatives. This paper concludes by identifying key lessons learned and recommending strategic approaches to ensure agroecosystem restoration remains a priority in global recovery and sustainability agendas.

1 Introduction

The purpose of the paper is to discuss the agroecosystem restoration opportunities to improve the environmental quality and new equilibrium that benefits the ecosystems needed in the biomass production process. The COVID-19 pandemic has had lasting impacts beyond public health, significantly influencing agroecosystem restoration worldwide. Disruptions to labour availability, supply chains, and agricultural inputs altered farming practices and land management, while economic pressures often reduced investments in sustainable restoration programs. At the same time, the pandemic highlighted the importance of resilient agroecosystems, encouraging greater attention to local food systems, biodiversity conservation, and ecological restoration as foundations for long-term food security and environmental sustainability.

At the end of December 2019, Covid-19 infected millions of people in Wuhan City, China. Furthermore, Covid-19 spread not only to several neighbouring China in January 2020, but it was also found in many parts of the continent of Europe, Australia, and America. Therefore, the case of Coronavirus infection has been determined by WHO as a global

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pandemic. There were 2,074,529 cases of disease and 139,378 causes of death in the world by the third week of February 2020 [1].

The world is now facing global biological disasters that have severely affected human activity, at the regional and global levels. The development of globalization, such as the loosening of formal borders between countries, makes it difficult to predict when this pandemic will end [2]. New cases of infection reported outside China indicate that the Covid-19 outbreak may become a new epicentre of the epidemic. However, some researchers have argued that animals are responsible for this virus infection. Thus, this virus infection occurs only between animals. This statement has however changed since the virus can adapt to the original human protein substratum. The transmission can take place between people and quickly becomes a social community epidemic in large cities.

This virus is first transmitted by the Hunan Sea Fish Market in Wuhan City which sells bats, snacks, dogs, raccoons, ferrets, and other cattle and the infection spreads rapidly to 109 countries [2]. Most coronaviruses infect animals, but their development can develop into new species carriers and, eventually, infect human beings as shown in Fig. 1. Recent developments have seen rapid growth in the transmission from human to human, especially when the human mass movement in the social masses grew, for example. Sneezing or coughing droplets attached to the surface of transport objects, restaurants, and other public places such as public toilets, elevators, lifts, or bus stops can be used as a transportation route between humans.

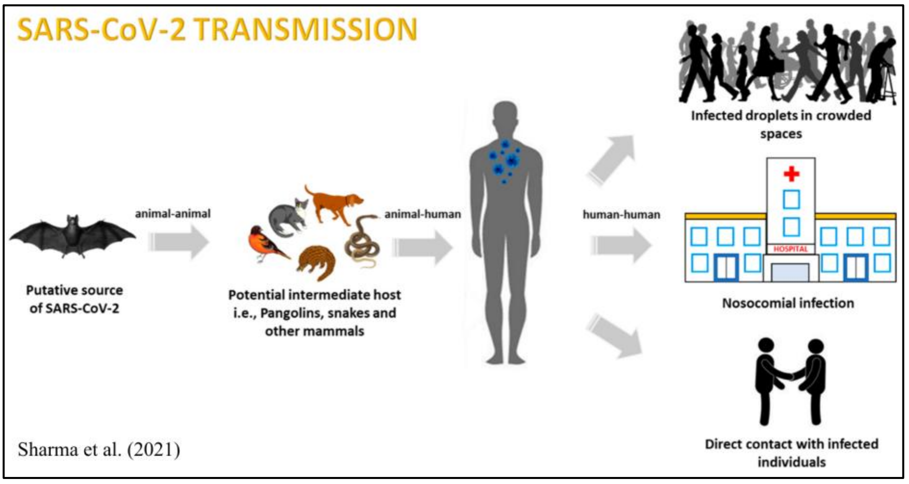

Fig. 1. Schematic illustration of zoonotic and human to human transmission of Coronavirus.

A covid-19 global pandemic, which has lasted more than four months, finally affected many aspects of life in many countries. Health disasters caused by the Coronavirus outbreak can negatively affect many sectors such as social, economic, food, services, and industry. The worldwide pandemic Covid-19 has the potential to instigate an unparalleled global recession. The OESC report dated 2 March 2020 indicates that global gross domestic product growth is projected to decline from 2.9 to 2.4 percent due to the global health crisis. In a more adverse scenario, the global gross national product might decrease to 1.5%, particularly if the viral spread impacts the United States and the European Union, resulting in a significant drop in stock markets and global oil prices [3].

The social pandemic situation can negatively impact the climate. Climate change will therefore threaten to change the world map of food production. Therefore, the global Covid-19 pandemic may, if this virus outbreak lasts for more than one season (6 months), disrupt the world's food supply programs and cause a food crisis. The Covid-19 pandemic can weaken lives, public health systems, livelihoods and economies worldwide, and thus people will experience a food crisis [4].

In April 2020, the Covid-19 pandemic has directly impacted the equilibrium between supply and demand for food and indirectly decreased a country's buying power and ability to produce food. Covid-19 will provide the global economy with more severe follow-up problems. The outbreak of the Covid 19 outbreak will systematically target all facets of economic activities, including the travel, public services, the sporting industries, dropping world oil and banking prices, and the financial technology industries [2]. As regards the effect of the Covid 19 pandemic on the sustainability of foodstuffs, there are at least four problems relating to the industry and the food chain: (1) consumers begin to think about ways of protecting themselves and the immune system through the introduction of sound food programs, (2) food chain protection from manufacturers, sellers and buyers, and (3) food security is a key issue because of lockdown policies so that more people stay indoors, and (4) the continuation of food supply during this pandemic is another attempt to limit the rise of other crises in the future.

2 Carbon Emissions and Climate Change

One of the causes of environmental pollution in the soil and atmosphere carbon imbalance. Carbon pollution and the increased ambient carbon concentrations contribute to climate change and changes in the atmospheric composition of gases [5]. Human actions on Earth's surface increase pollution releases in the form of carbon monoxide and carbon dioxide. The carbon concentration of the carbon monoxide gas will disturb the ozone composition, causing a growing percentage of short-wave radiation into the earth's orbit. In the meantime, carbon dioxide will form a CO2 gas membrane that cannot be penetrated by planetary heat (longwave radiation). The surface heat is absorbed into the climate system and can heat the lower atmosphere.

The rise in carbon in the atmosphere will stimulate climate change processes that correlate with broader impacts on the ecosystem. In the IPCC, global temperatures are continuing throughout the 21^{st} century to increase from 1.1 to 6.4°C and the distribution of rainfall patterns will change [6]. Climate change could lead to a range of problems including global warming, ecological imbalance, technological progress, and economic and social growth. The release of carbon deposits from the soil determines the carbon concentration in the atmosphere. The distribution and percentage of carbon fixation by photosynthesis of plants on the earth’s surface influences the carbon stock as biomass and soil organic matter. The carbon cycle in nature affects carbon emissions and climate change, as seen in Fig. 2.

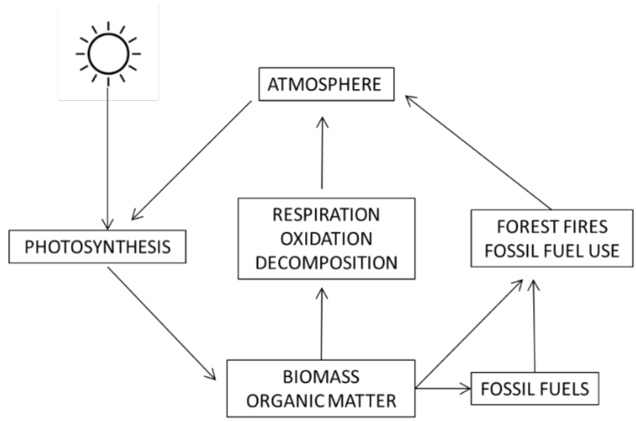

Fig. 2. Process of carbon cycle in nature.

Fig. 2 illustrates that carbon emissions, which can elevate atmospheric carbon concentrations, are influenced by terrestrial surface activity. Photosynthesis serves as the primary mechanism for atmospheric CO2 fixation, contributing significantly to the soil's carbon stock. Natural processes, including respiration, oxidation, and the decomposition of organic matter, will release typical CO2 into the atmosphere. Human activities related to land production, fossil fuel consumption, and forest fires exacerbate carbon emissions. Human requirements for food, coupled with technological advancements, will significantly decrease carbon stocks in the soil via industrial methods. The intensification and expansion of diverse human activities necessitate property, serving as a dependable industrial mechanism and the primary source of capital and resources. Demands for food supply to accommodate global population growth are resulting in heightened land pressures and burdens. The land extension will alter the carbon stock of the soil.

In certain tropical countries, the use of organic soils can also release carbon dioxide into the atmosphere. Land type and land use significantly influence the global carbon stock, as soil organic carbon plays a crucial role in the carbon cycle. The land serves as both a source and a reservoir of greenhouse gases, which are integral to the exchange of electricity, water, and aerosols between soil and atmosphere. Soil organic carbon stocks are decreasing, while those in forest systems are increasing [7]. The organic carbon content can contribute to the emission of greenhouse gases through soil and biological processes. Agricultural land management affects soil carbon stocks and the biological cycle of carbon elements; thus, any form of soil use can either decrease or increase atmospheric greenhouse gas concentrations.

Both natural and anthropogenic forest fires significantly impact climate change. Carbon emissions into the atmosphere can exacerbate deforestation in tropical regions and other areas globally. Deforestation contributes to climate change by halting the CO_2 fixation capacity of forest vegetation when trees are burned or cleared for specific purposes, thereby failing to reduce atmospheric carbon concentrations. Human activity on the Earth's surface and the release of carbon dioxide into the atmosphere are interconnected factors that contribute to global warming and drive climate change. Experts have concentrated on the interplay between climate change and soil carbon resources, as well as on identifying strategies to mitigate the effects of carbon emissions on climate change.

The industrial sector is advancing swiftly in the production of primary and secondary goods. The rapid development of the industrial sector may enhance fossil energy consumption and result in the emission of carbon into the atmosphere. China is positioned as the largest carbon emitter due to its manufacturing sector [8]. Carbon emissions rose from 1.91 billion tons in 1995 to 6.25 billion tons in 2015, reflecting an average annual growth rate of 6%. The provision of infrastructure in major global cities necessitates a substantial energy supply, and the utilization of this energy correlates directly with the carbon emissions generated by each nation. Beijing ranks among the world's major cities, serving as a significant consumer of energy and a notable producer of carbon emissions.

The Integrated Carbon Observation System (ICOS) in 2019 states that from year to year there is an increase in the release of fossil carbon emissions by human activities on the surface of the earth (Fig. 3). Fig. 3 indicates that carbon emissions into the atmosphere increased to 36.8 Gt of CO_2 in 2019, representing a substantial contribution to global warming and climate change. A strategy for reducing carbon emissions involves managing carbon stocks in the soil. Carbon management in soils is a critical strategy for enhancing ecological health and influencing climate change dynamics, as soil plays a vital role in carbon cycling and serves both as a contributor to climate change and a receptor of its effects [9]. Maintaining carbon stocks in soil positively influences global food security, enhances environmental services, improves the quantity and quality of freshwater, and increases biodiversity.

The concept of soil health and productivity is related to carbon management that some soil functions and ecosystem support depend on the dynamism of soil organic matter content. Improved soil health can increase soil resilience to extreme climates [9]. Soil health is closely linked to carbon management. Carbon management practices that increase soil carbon sequestration can enhance soil health by improving soil structure, increasing water holding capacity, and promoting the growth of beneficial soil organisms. In contrast, effective soil management can enhance carbon storage and reduce greenhouse gas emissions. Enhancing carbon sequestration in soil through practices that promote soil biodiversity, such as reduced tillage, incorporation of organic matter, and utilization of cover crops, can lead to improved carbon management. Furthermore, the preservation of soil biodiversity enhances crop yields, improves soil health, and increases the resilience of agricultural systems to climate change.

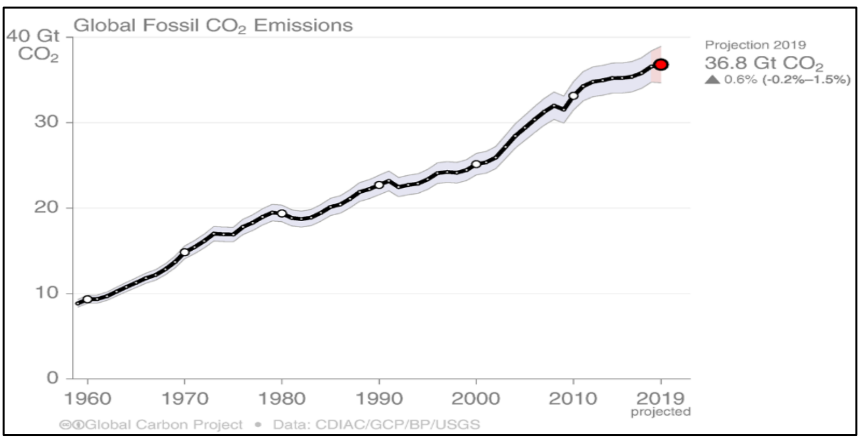

Fig. 3. Annual global fossil CO2 emissions reported by Global Carbon Project.

3 The Impact of COVID-19 Pandemic on Agroecosystem Restoration

Climate change and global warming affect farming, particularly land use and ecosystem conditions. The interaction of agriculture and ecosystems is a major concern in the estimation of climate change impacts. The key concern is how climate change and its future changes both individually and interact in agriculture and ecosystems. Minimizing the detrimental effects of climate change on the production of biomass is the policy. Mitigation has culminated in climate change adaptation and mitigation measures. The ecosystem is a natural shield for all forms of life on the planet from extremes such as drought and flooding. Ecosystems directly influence the reproduction and distribution of species, of biodiversity, on the surface of the earth [10].

Climate change alters ecosystem conditions, necessitating adaptation or leading to extinction for all life forms on the surface. Climate change impacts biomass production patterns and food chains within a region. The mitigation strategy was accomplished through the development of plant species resistant to emerging climate stressors. Sustainable land use that minimizes carbon emissions concurrently supports the mitigation strategy. Efforts have been initiated to adjust to emerging climate trends, including the cultivation of drought-resistant plant varieties, modifications in crop systems and planting schedules, diversification of flora and fauna, transitions from monoculture to polyculture, reforestation and agroforestry practices, as well as improved groundwater management and rainwater harvesting techniques.

An agroecosystem represents the interaction between agricultural production processes, specifically biomass production, and the surrounding environmental conditions within the agricultural ecosystem. An agroecosystem is a landscape where interactions occur among the atmosphere, plants, flora and fauna, soil, and water. The conditions that characterize these interactions are referred to as agroecology. The intensification of agroecosystems aimed at enhancing food production and agricultural commodity yields can lead to the conversion of organic carbon stocks in the soil, resulting in their release into the atmosphere. Agriculture accounts for approximately 30% of anthropogenic greenhouse gas emissions that contribute to climate change. Alterations in the Earth's surface resulting from agricultural practices and the conversion of organic carbon to inorganic carbon, manifested as carbon gas emissions, contribute to the deterioration of environmental service quality, primarily due to a reduction in biodiversity.

Agricultural activities can affect more than 40% of the land on the planet earth, and this is a major problem of reduced biodiversity on the earth's surface [11]. The release of CO2 into the atmosphere causes an increase in greenhouse gases, due to the absorption of heat in some infrared heat waves emitted by the earth's surface. Carbon dioxide plays an essential role in natural heating greenhouses in the atmosphere. All forms of land use can change the balance of organic carbon stocks and inorganic concentrations of carbon in the atmosphere. Between 1990 and 2010, net carbon flux from the land surface and land conversion ranged from 12.5% of all anthropogenic carbon emissions [12]. Many agro-ecosystem functions provide various forms of ecosystem services such as regulation of water and soil quality, carbon sequestration, support for biodiversity, and socio-cultural services. Therefore, fluctuations in agro-ecosystem quality can affect the quality of ecosystem services to biomass production and, on a broader scale, determine the socio-cultural conditions on the earth's surface.

Climate change illustrates the pattern of changes in temperature, rainfall, and atmospheric CO_2 concentrations. Temperature, precipitation, and CO_2 levels are natural phenomena that occur in the climatic system and are the main components that determine the quality of the ecosystem. Thus, climate change can reduce the quality of the environment in providing support to agroecosystems. Future climate change and variability will, in principle, affect agroecosystems throughout the earth's surface and affect plant growth and yield due to increased atmospheric CO_2 concentrations and higher temperatures [13]. Climate change can change rainfall patterns, both season, duration, intensity, and amount. While on the other hand, climate change also causes an increase in average annual temperatures across the earth's surface. The increased temperature on earth makes the process of evaporation from the land surface, and respiration on plant surfaces can increase so that the pattern of water balance in an agroecosystem complex can be disrupted. In this case, climate change can cause an increase in temperature and rainfall patterns and can change the hydrological, ecology, biology, and geographic conditions that affect the services and support provided by agroecosystems [14].

The Covid-19 pandemic has grown into a human-to-human outbreak. To reduce human interactions, numerous countries have implemented social and physical distancing measures. Social distancing can negatively impact economic growth and contribute to the acceleration of recession. Transmission of viruses among individuals can result in asymptomatic carriers. The implementation of social interaction restrictions is contingent upon the severity of transmission. Limitations in social communication may manifest as social distancing, quarantine, and isolation. In a lockout environment, substantial and unregulated transmission volumes would necessitate quarantine measures and complete insulation.

The lockdown will gradually slow down or even stop all activities within and between countries. Lockdowns can dramatically reduce human mobility from a social point of view. When carbon emissions are released, a lockdown will reduce carbon emissions as the factories and transport sectors stop running. Reducing carbon emissions will minimize greenhouse gas concentration in the atmosphere, contributing to better air quality. The lockdown is an attempt to restrict human movement and to reduce the spread of this virus and has immense environmental impacts [15]. The reduction in manufacturing and transport activities greatly decreases industrial waste and greenhouse emissions as fossil fuels are reduced.

The ecosystem's health has shown significant recovery, and there is potential for improvement in the ozone layer. In March and April 2020, air quality improved significantly in most major cities due to a decrease in CO_2 emissions, nitrogen oxides, and other particulate matter. The international connections between the population and flight schedules would significantly diminish over time. Global air traffic decreased by 60% during this period, contributing to a temporary reduction in CO_2 emissions. The decline in human surface activity may also impact air quality and lead to a decrease in greenhouse gas emissions as shown in Fig. 4.

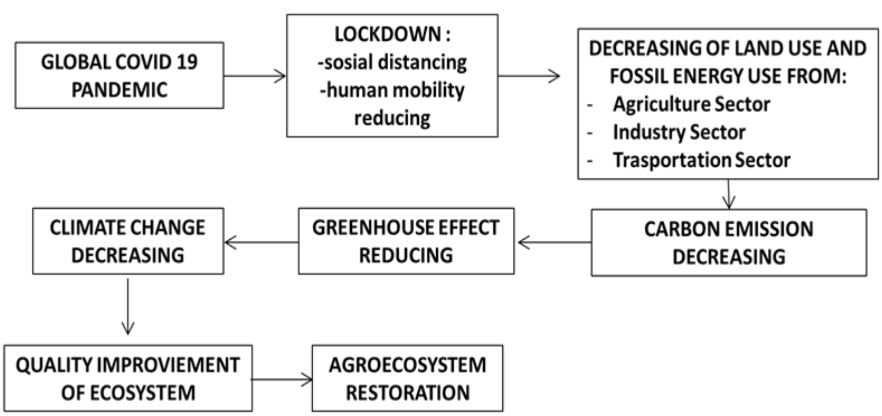

Fig. 4. The relationship between the policy of Covid-19 pandemic and agroecosystem restoration.

Social constraints impact the decline of land intensification and agroecology that can affect the production of biomass. Farming on the other hand plays a crucial role in shaping the patterns of human migration [4]. The migration of individuals significantly influences the food distribution chain. Social restrictions aimed at reducing the spread of coronavirus directly affect food transport and disrupt the food distribution process. Comprehensive social restrictions would limit surface transportation rates and decrease carbon emissions.

During 2020, there has been a reduction in CO_2 emissions worldwide. Fig. 5 shows the relationship between the explosion of the Covid-19 outbreak (January-February 2020) and the establishment of a social limit (lockdown) in March-April 2020, which results in a decrease in the concentration of CO gas in the atmosphere. This decrease in CO gas concentration indicates a reduction in the use of energy sources on the earth's surface. Due to the Covid-19 outbreak, there could be a decline in the use of various energy sources on the surface of the earth as shown in Fig. 6. The expected decreased energy demand in 2020 will contribute to improved air quality. The environment is cleaner and healthier, reducing climate change and rising the efficiency of the ecosystem. The quality of the environment can be enhanced by reducing the human interest in land and by reducing CO_2 emissions. Improving ecosystem quality will speed up the restoration of agroecosystems to increase the quality of environmental services.

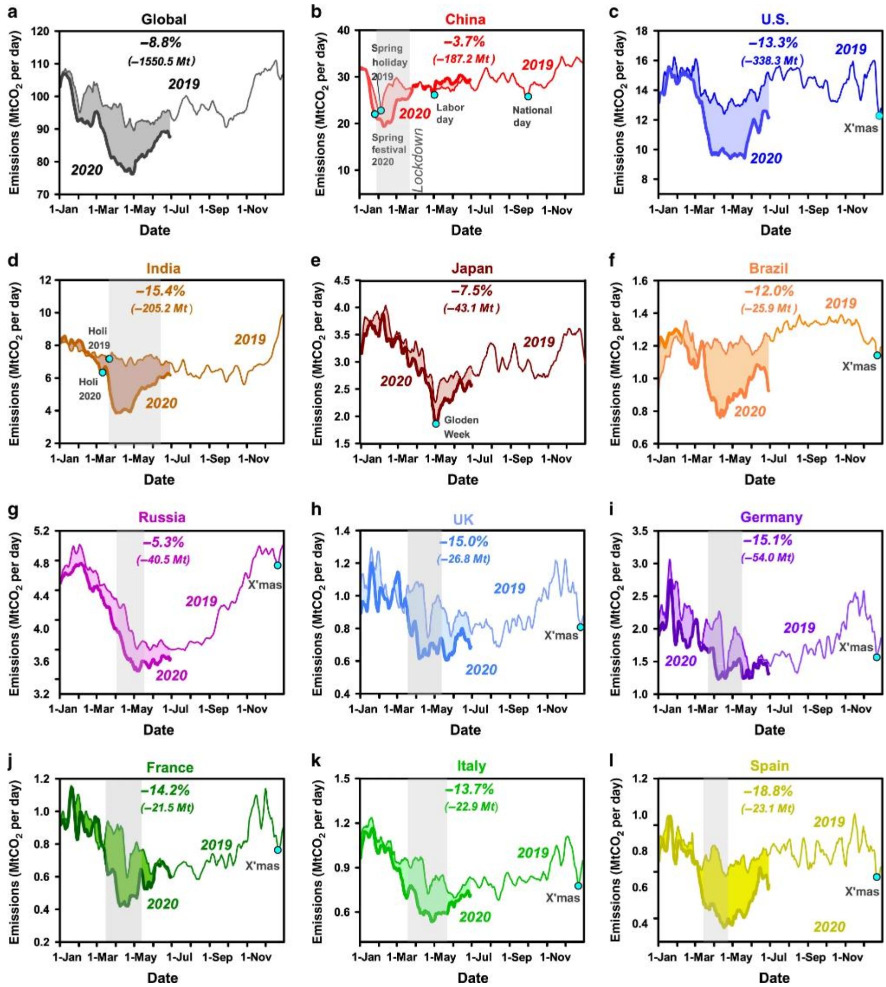

Fig. 5. Comparison on global CO_2 emission among several countries during COVID-19 period in 2020 [41].

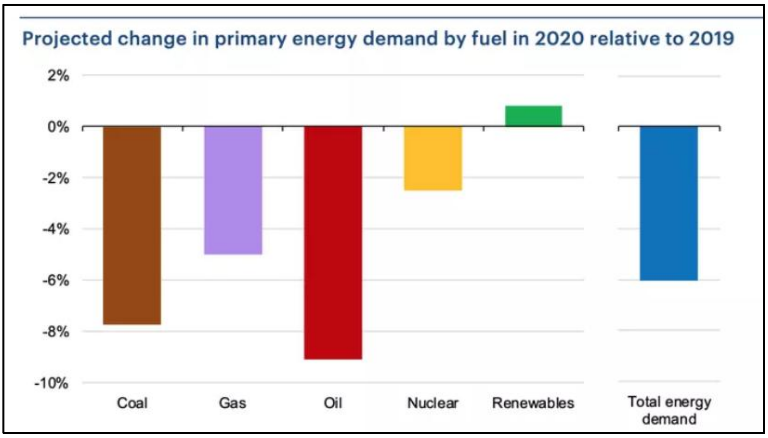

Fig. 6. Projection of energy demand in 2020 reported by International Energy Agency [42].

4 Conclusions

The global Covid-19 pandemic has rapidly altered the surface of the world. The production and distribution of goods, human interaction, and transportation among countries, along with energy consumption and environmental pollution, have significantly decreased due to a reduction in pollutants and carbon emissions. Between February and June 2020, human impacts on the Earth were reduced, allowing for more effective preservation of natural cycles. Reducing CO2 emissions will significantly improve environmental quality by enhancing ecosystems. The agroecosystem's condition can be rehabilitated through the interplay between agriculture and ecosystems. In conclusion, the COVID-19 pandemic disrupted agroecosystem restoration efforts but also underscored their importance for resilient and sustainable food systems. The crisis highlighted the need for locally adapted, agroecological restoration approaches that strengthen soil health, biodiversity, and long-term resilience.

References

1. World Health Organization, World Health Organization. 26, (2020).
2. A. Faiza, *Walaiak Journal of Science and Technology* 17**,** 958-66 (2020).
3. OECD Interim Economic Assessment, Coronavirus: The world economy at risk. Organisation for Economic Co-operation and Development. (2020).
4. FAO, Addressing the Impacts of COVID-19 in Food Crises, April–December 2020: FAO's Component of the Global COVID-19 Humanitarian Response Plan. FAO Rome. 2020.
5. L. Pothiban, R. Chintanawat, N. Wongpakaran, C. Srirat, K. Sucamwang, Walailak Journal of Science and Technology (WJST). 17, 1066-76 (2020).
6. E. C. Brevik Agriculture. 3, 398-417 (2013).
7. M. Stergiadi, M. Van Der Perk, T. De Nijs, M. F. Bierkens, Biogeosciences. 13, 1519-36 (2016).
8. J. Liu, Q. Yang, Y. Zhang, W. Sun, Y. Xu, Sustainability. 11, 226 (2019).
9. R. Lal, Carbon Management. 4, 439-62 (2013).
10. S. D. Nurtjahyani, D. Oktafitria, N. M. Sriwulan, I. Cintamulya, E. Purnomo, Advances in Tropical Biodiversity and Environmental Sciences. 4, 21 (2020).

 https://doi.org/10.1051/bioconf/202622702005

11. M. P. Barral, J. M. R. Benayas, P. Meli, N. O. Maceira, Agriculture, Ecosystems & Environment. 202, 223-31 (2015).
12. R. A. Houghton, J. I. House, J. Pongratz, G. R. Van Der Werf, R. S. Defries, M. C. Hansen, et al. Biogeosciences. 9, 5125-42 (2012) .
13. M. A. Altieri, C. I. Nicholls, A. Henao, M. A. Lana, Agronomy for Sustainable Development. 35, 869-90 (2015) .
14. S. Pokhrel, J Environ Sci. 4, 92-104 (2018).
15. I. Chakraborty, P. Maity, Science of the Total Environment. 728, 138882 (2020).