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A Comprehensive Review of the Impact of CO_2 Emissions on Global Warming and the Potential Using Solar Energy Mitigation

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ABSTRACT

Carbon dioxide (CO_2) emissions are the principal cause of global warming, a serious environmental issue with far-reaching implications. This extensive assessment investigates the multidimensional influence of CO_2 emissions on global warming, looking at both the scientific basis and the possibility for solar energy as a mitigation approach. The evaluation focuses on solar energy's ability to reduce CO_2 emissions and combat global warming. It investigates the benefits of solar energy as a clean, renewable, and sustainable source of electricity. The evaluation assesses the current state and future prospects of solar technology, focusing on its cost-effectiveness, scalability, and environmental benefits. Furthermore, the assessment looks at the obstacles and potential connected with solar energy deployment. It emphasizes the importance of legislative assistance, infrastructural development, and technology developments to hasten the transition to solar energy. The evaluation also evaluates the possible synergies between solar energy and other renewable energy sources as part of a comprehensive approach to CO_2 emissions reduction. Finally, the assessment highlights the critical necessity for a worldwide response to the climate catastrophe. It advocates for bold and collaborative efforts to cut CO_2 emissions and transition to sustainable energy systems, with solar energy playing a critical role. The review is an invaluable resource for policymakers, scientists, and stakeholders interested in the impact of CO_2 emissions on global warming and the possibilities of solar energy mitigation.

1. Introduction

Global warming, a pressing environmental issue, is largely driven by the increased concentration of greenhouse gases, particularly carbon dioxide (CO_2), in the Earth's atmosphere [1]. The combustion of fossil fuels, a primary energy source for human activities, has led to a substantial rise in atmospheric CO_2 levels, from the preindustrial level of 280 ppm to 420 ppm in 2023 [2]. This accumulation of CO2, along with other greenhouse gases, traps heat and alters the planet's climate patterns, causing widespread environmental changes [3]. Addressing the challenge of global warming requires a multifaceted approach, with carbon capture and storage technologies playing a crucial role. Conventional CO_2 capture methods have primarily focused on point sources, such as power plants and industrial facilities [4]. However, a significant portion of CO_2 emissions also comes from mobile sources, making direct

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air capture a viable option for reducing atmospheric CO_2 levels [2].The most recent developments in carbon capture and sequestration technology may also help limit and regulate the release of greenhouse gases that are caused by humans [5]. Carbon dioxide emissions from factories or power plants are captured using carbon capture and sequestration technologies, which then store the carbon dioxide underground or in other long-term storage options [6]. Large-scale demonstration projects and a substantial investment in research and development are necessary for the adoption of these technologies, albeit [7]. One possible method, for instance, is membrane technology, which uses selective membranes to extract CO_2 from gas streams, including those from fossil fuel power plants [8]. Up to 90% of the CO_2 that is released can be retained thanks to the selective membrane's ability to distinguish CO_2 from other gases in the gas stream [9]. Furthermore, in comparison to other carbon capture systems like adsorption or chemical absorption, membrane technology is thought to be less expensive and simpler to maintain [10]. Nonetheless, it is crucial to remember that laws and rules encouraging the use of these technologies are also required to hasten their implementation and guarantee their efficacy in lowering greenhouse gas emissions [11]. Solar energy, a renewable and clean energy source, holds immense potential in mitigating the effects of global warming. In developing countries, the utilization of solar energy can significantly reduce energy-related emissions, easing the burden of energy production and addressing local environmental concerns [12]. The widespread adoption of solar energy technologies can contribute to the reduction of greenhouse gas emissions, particularly in regions that heavily rely on carbon-intensive fuels to meet their energy demands. The integration of carbon capture and storage technologies, coupled with the implementation of solar energy solutions, presents a promising pathway to address the pressing issue of global warming. By reducing CO_2 emissions from both point sources and the atmosphere, and transitioning to clean, renewable energy sources, we can work towards a more sustainable future [2, 4, 12]. In this article we will scope on the climate science through the study of the Earth's climate system. It focuses on understanding the dynamics of climate, including the natural and anthropogenic factors that influence climate change. This field involves the collection and analysis of data from various sources, such as ice cores, tree rings, satellite observations, and climate models, to understand past, present, and future climate conditions. CO_2 emissions have significantly increased since the Industrial Revolution, primarily due to the burning of fossil fuels (coal, oil, and natural gas) and deforestation. The concentration of CO_2 in the atmosphere was about 280 parts per million (ppm) before the Industrial Revolution. Today, it has exceeded 420 ppm. Major contributors to historical CO_2 emissions include industrial activities, transportation, electricity production, and agriculture mitigation strategies and focusing on solar energy potential. As we strive to mitigate the impacts of climate change, it is crucial to explore and implement a diverse range of technological solutions, including carbon capture and the widespread adoption of solar energy.

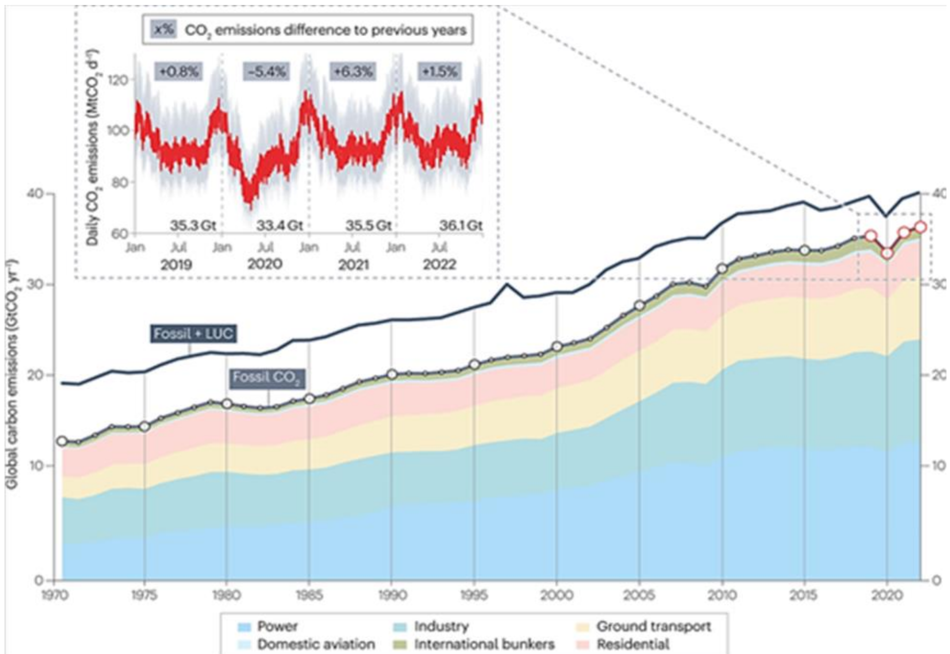

Figure 1: Global CO_2 emissions 1970–2022. Historical CO_2 emissions from fossil fuel combustion and the process of cement production (‘Fossil CO_2’) [13] colored by industry sector, and those with land-use change (LUC) emissions (‘Fossil + LUC’). International bunkers describe emissions from international aviation and international shipping. The inset displays daily near-real-time CO_2 emissions since 2019 from the Carbon Monitor1,2 initiative and year-on-year percent changes. Note that total emissions and percent changes have been revised slightly from earlier estimates3. Global CO_2 emissions continue to grow after a brief decline in 2020, which if it persists, it will use up the remaining 1.5 °C carbon budget within 2–7 years [14].

2. The Science of CO_2 Emissions and Global Warming

Degradation of the environment due to careless CO_2 emissions is a problem that many developing nations have been facing recently [15]. The rapid industrialization and urbanization in many emerging nations has resulted in a rise in atmospheric carbon emissions from industrial activity. Anthropogenic greenhouse gases, such CO_2, have been found to significantly increase in atmospheric concentrations due to this, which in turn has caused climate change and global warming. Climate change leads to reduced agricultural productivity in the world because of reduced rainfall, changes in seasons, and temperature increase [16]. A lot of regions of the globe are arid and are no longer suitable for commercial farming as a result of climate change. Unrelenting temperature and precipitation fluctuations are also expected to cause enhancement of the rates of soil and water degradation. But one can reduce these effects via adaptive behavior because land use and management have been found to have a more significant effect on the state of the soil than the effects of climate change [17]. This indicates that climate change will proceed even if all emissions from human activities were to suddenly end[18]. Climate change, ocean acidification, desertification, and altered weather patterns could be exacerbated by the current level of human-caused pollution and the haphazard emission of greenhouse gases into the atmosphere. However, further prospective effects of climate change include threats to food security, increased risk of flooding and other severe storms, health problems, migration, and economic losses [5].

It is released when fossil fuels such as coal, natural gas and oils, solid waste, trees, and any organic material is burnt[19]. Further, certain chemical reactions (like cement manufacturing) might result in the emission of CO2. Additionally, human actions have the potential to change the carbon cycle, increasing atmospheric CO2 levels and influencing the efficiency of natural carbon sinks, such as forests. The majority of human-caused carbon dioxide emissions come from burning fossil fuels for power and transportation, but changes in land use, including deforestation, also play a role[20]. Carbon dioxide is also taken out of the environment (or sequestered) through the normal processes of the carbon cycle, for instance, through plant uptake. Nevertheless, carbon capture, storage, and usage can reduce emissions from immobile point sources like cement and power plants. Burning biomass materials with coal in coal-fired power stations is another practical approach to lowering CO2 emissions [21].

The need for electricity increased during the industrial revolution, and by the turn of the millennium, power generation had increased by about 50%[22]. In 2002, the estimated worldwide CO_2 emissions from fossil fuels reached about 25,000, metric tons. The use of fossil fuels will increase by over 90% and continue to be the primary source of energy[23]. This suggests that energy consumption is on the rise globally, and that trend is predicted to continue and even pick up speed, reaching over 67% by 2030.[24]. Therefore, it is critical to identify the major sources of CO2 emissions and develop strategies to mitigate them. Table 1 displays, many sources of CO_2 emissions and potential solutions to lower these emissions. The information provided indicates that the combustion engines of fossil fuels and coal-fired power stations are the primary sources of anthropogenic CO2 emissions to the atmosphere. This study suggests that carbon capture, storage, and use (CCSU) is the best way to prevent CO2 emissions, since most of these emissions come from stationary point sources.

The main idea behind carbon capture and storage units (CCSUs) is to divert CO_2 emissions from big, stationary sources like power stations that burn coal or gas and send them somewhere it can't go back into the air [19]. Here are some of the most significant ways in which the combustion of fossil fuels releases carbon dioxide and other greenhouse gases.

• **Power industry**: Coal and natural gas are two examples of fossil fuels often burned to generate electricity in power stations that use this technology. The power industry will keep releasing massive amounts of CO2 into the air unless we find other, cleaner ways to generate electricity, including nuclear power and solar panels.

• **Transport industry**: Air pollution is a major contributor to climate change and global warming. Fossil fuels like coal, diesel, and gasoline are burned to power vehicles, trains, and aero planes. Vehicle-emitted carbon dioxide emissions are quite intense and non-stationary. The most practical way to decrease CO2 emissions from this industry up to now has been to replace fossil fuels with bio-based alternatives or to switch to electric vehicles entirely[25].

• **Buildings**: Emissions of these gases, which include CO2, CH4, and SO2, are released into the atmosphere from many sources in the commercial, residential, and industrial sectors. The most common of these sources are the disposal of waste, the combustion of fossil fuels for energy purposes, and the use of items that contain these gases. No unique technology has been recorded to reduce CO2 emissions in houses and other enterprises as far as the author is aware[5].

Table 1 : Major sources of CO2 emission and their preventive methods[12].

Sources	CO2 emission (billion Mt)	Proposed preventive option
Anthropogenic/human sources		
Fossil fuel combustion engines	392	CCSU
Cement production plants	113	CCSU
Power generation (coal-fired power plants)	279	CCSU, integration to methanol plant
Transportation	191	Blending fuels with biomass
Industrial manufacturing	178	CCSU
Land use changes	13	–
Nonanthropogenic/natural sources		
Plant, animal, and human respiration	7	–
Ocean-atmosphere exchange	7	–
Soil respiration and decomposition	1.54	–
Volcanic eruptions	0.15	–

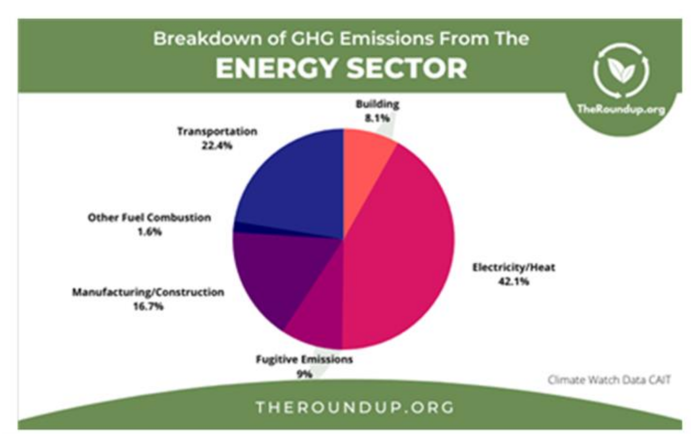

Figure2:Greenhouses emissions from the energy section [26].

3. Historical and Current Trends in CO2 Emissions

Managing the short-term and long-term impacts of crises on decarbonization is crucial, as shown by the present energy and economic crisis in Ukraine and the economic disruption caused by the COVID-19 pandemic[27, 28]. By mid-century, all countries must have reduced their carbon dioxide (CO2) emissions to zero if they are to meet the goals set out by the Paris Agreement A large body of research on emissions drivers[29-31] and decoupling confirms that several nations, mostly in Europe, have reached their CO2 emission peaks and are now beginning to lower them. The significance of economic crises is one of the many unknowns when it comes to the timing of peaks; however, the limited number of empirical assessments that do exist suggest that crises did not slow down the decarbonization process[27, 32]. Nevertheless, conceptual analyses from various fields suggest that national economies and energy systems can undergo structural changes in response to crises. These changes affect both the economy and the technologies used, particularly energy technologies, which are influenced by policy and economic factors. We examine the impact of previous crises on structural change that contributes to national (territorial-based) emissions peaks in this paper. Many theoretical considerations point to the possibility that the interplay between the political, economic, and social domains would be so strained during a catastrophic economic downturn that decarbonization's necessary structural transformation would be accelerated. What economists from the Schumpeter school call "creative destruction”[33] is a driving force behind systemic shifts. In a recession, less efficient assets (or industries) may vanish, never to be seen again, supplanted by newer, more productive alternatives. The result is a long-term reduction in emissions and structural change because these "creatively destroyed" assets are typically the least energy- or carbon-efficient ones. Thus, unlike in "business as usual," policy "windows of opportunity" and "critical junctures" can be created during crises to address energy and climate change. The implementation of Green Keynesianism-based green recovery packages may also be prompted by a crisis[34-38]. From transition studies point of view, external landscape shocks such as economic shocks can disrupt socio-technical regimes and bring about a change and transition to another regime which is a lower carbon regime in this case[39]. Therefore, there are sound theoretical reasons to believe that economic crises are, because they are disruptive, the type of regime change that is required for decarbonization.

However, other authors state that crises may have a negative impact as they raise uncertainty and, therefore, can deter private investment, particularly in emerging technologies that are inherently risky[40, 41]. For decarbonization methods that need a lot of investment, this may be disastrous. Also, after a crisis, politicians focus less on long-term issues like climate change and more on short-term issues like getting the economy back to where it was before the downturn[42], to the recovery of the economy as it was before the recession[43]. A crisis may reduce emissions temporarily due to lower economic activity, but this effect would not last. Instead, these effects would mostly serve to stabilize the economy, which is bad news for structural change. As a result, the purported effects of crises are unclear and might have positive or negative effects for decarbonization [44].

Global CO_2 emissions from human activities are now at the highest they have ever been in recorded history. For instance, current statistics show that global CO_2 emissions in 2022 were 182 times higher than those in 1850 – during the early stages of the industrial revolution.

To predict when carbon emissions will peak, scientists mostly use the environmental Kuznets model[45], scenario analysis[46] and IPAT model [47, 48]. Different researchers came to different results when they used the aforementioned distinct approaches to study China's peak carbon emissions and when they occurred. In order to determine the best period for each of eight Chinese sectors, Fang et al., used carbon emissions data from 1995 to 2017 and tested the environmental Kuznets curve theory. For their mixed-model variable-value forecasting and scenario-building, Meng et al.[49] examined the environmental Kuznets curve hypothesis for these sectors and predicted the optimum time for each sector. Meng et al.[50] employed log-linear equations in a mixed model to forecast the values of variables and establish five scenarios. Their findings indicate that China's power sector will not achieve its peak emission level by 2030. Using the LEAP model, Hernández and Fajardo[51] established three scenarios to estimate carbon emissions and carbon intensity in 2050. Tang et al. [52] divided six regions according to their geographical location, evaluated the influence of technical factors and energy consumption on CO2 emissions from the regional power sector, and investigated the carbon peak time. This was done from a regional perspective. Chang et al.[53] employed scenario analysis to assess three carbon emission reduction scenarios from the perspectives of social equity, emission reduction efficacy, and forest carbon sink. The results show that under the 2030 carbon emission target, the marginal CO_2 emission reduction cost is 2315–5387 yuan[54].

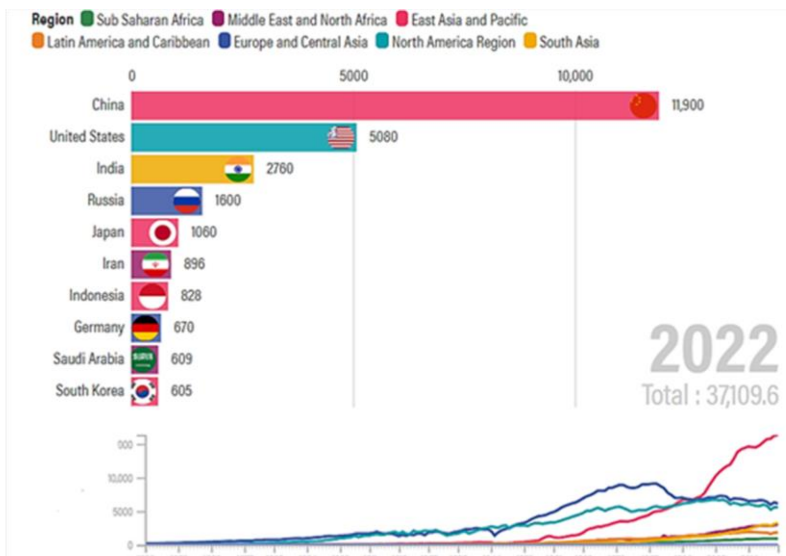

Figure 3: CO_2 Emissions by Country, 1850-2022(MtCO2)[55]

4. Consequences of Global Warming

Surface warming is contributing to the phenomenon of increasing sea levels around the world and the melting of the polar ice cap. Moreover, as a result of global warming, we should expect an increase in extreme precipitation and droughts as well as a decrease in or alteration of precipitation patterns that are beneficial to agricultural output. Several parts of the world are already experiencing tropical cyclones, severe flooding, and prolonged droughts as a result of the increased air temperature, sea level, and extreme precipitation events brought about by global warming. Tropical cyclones, floods, and droughts are becoming more common, and they are expected to do significant damage to water supplies, agriculture, and the vital infrastructure (such as schools, hospitals, and businesses) that supports our contemporary society. The 2018

Japanese floods are instructive from an industrial standpoint because they caused the explosion of an aluminum mill as a result of the interplay of floodwaters[56]. The explosion of this aluminum plant leveled homes and set fires up to a radius of around 180 meters[56]. The release of 80 tons of dangerous chlorine from a tank at a Czech Republic plant was triggered by the buoyant force of floodwaters. This caused the destruction of soil, water, crops, and fields in the surrounding districts, leading to significant economic losses [57].

The link between outside temperature and the frequency and severity of strokes has conflicting findings. Some researchers have found that certain forms of stroke are more likely to occur in very hot or cold climates; others have found that the incidence of stroke varies with the seasons and others have rejected the idea that environment plays a role in the development of stroke[58, 59].

Results from a four-year study of emergency department visits to three Beijing hospitals revealed that low temperatures increased the risk of intracerebral hemorrhage (ICH) in a younger group of patients (38–48 years old) whereas high temperatures increased the risk of ischemic stroke (IS) in a more senior group of patients (38–78 years old)[60]. According to retrospective research that looked at data from the last decade, there was conflicting evidence that showed a 3% reduction in the risk of IS with a 1 ◦C increase in winter temperatures and a 15% increase in the risk of ICH in summer[61].

Aggregate loss functions, used in standard models of global warming, connect the dots between the future of the economy as a whole and the changes in climate variables. These loss functions often ignore the ways in which people and businesses act. Functions like these ignore the fact that households and businesses may adjust, albeit at a cost, to the most noticeable effects of climate change since they are not based on micro-founded models that find optimal behavior in response to these shocks. The tremendous heterogeneity that increasing temperatures will have on the economy's foundations makes it all the more crucial to incorporate these responses [62]. Additionally, it is crucial because, as an expression of the Lucas critique, only a model that specifically considers these regional behavioral adaptation responses can accurately predict how aggregate loss functions might change in policy counterfactuals and simulations of different scenarios[63]. Consequently, the field of climate change economics requires a quantitative dynamic model such as ours, which incorporates individual behavioral reactions and explicitly accounts for spatial variability at a high resolution.

Utilizing panel techniques and capitalizing on short-run weather variance, numerous empirical assessments of climate damages have been published in the past ten years. These studies aim to determine the causal effect of temperature on economic and social outcomes. Deschenes and ˆ Greenstone [64], were the first to publish empirical articles in this wave, and they examined how temperature affected agricultural earnings. Quantifying the effects of weather on mortality[65, 66], amenities [67], [68] crime and conflict [69], migration [70], crop yields [71], GDP and GDP growth [69, 72] have all been done using this methodology. Though helpful in establishing a correlation between temperature and economic results, this research does not allow us to forecast regional temperature impacts or compare various approaches. Some of these estimates have been Integrated Assessment Models (IAMs), which attempt to quantify the monetary effects of climate change, have used some of these estimations. One key difference is that, whereas we focus on the impact of global warming on local capital investments, Krusell and Smith[73], examine a comparable spatial resolution but take a different approach. In contrast to previous work, we estimate harm functions on productivities and amenities instead of GDP and explicitly include migration, population expansion, commerce, and innovation.

A variety of aspects of climate change have been examined by expanding upon these fundamental models. Research by Popp, Acemoglu et al., Acemoglu et al., Hassler et al.[74-78] evaluates the impact of investments and developments in clean technology on reducing climate impacts. Research by Benveniste et al.[79] investigates how much protection from climate change affects migration and border policies provide. The ability to satisfy food demand under various climatic change scenarios is examined by Dietz and Lanz[80]study the capacity to meet food demand for different climate change conditions. Fried [81] assesses the function of adaptive capital investment in mitigating the effects of severe weather. Taking into account extreme estimates for the climate sensitivity and economic damages, Hassler et al.[82] compares the ideal carbon prices to the warming-induced GDP losses. The agricultural sector's losses due to authorized adjustments in trade and production patterns among crops are examined by Costinot et al.[83] The ideal environmental policy when distortionary taxes are present is studied by Barrage [84] studies the optimal environmental policy in the presence of distortionary taxes.

Figure 4:consequences of climate change[85].

5. Mitigation Strategies

The stability of the CO_2 concentration equilibrium in the atmosphere can no longer be guaranteed by these natural processes due to the rise in anthropogenic CO_2 emissions [86]. A sustained rise in atmospheric CO_2 concentration has resulted from ongoing CO_2 emissions, which has prompted worries about the effects of climate change on Earth [87]. This emphasizes the significance of implementing efficient mitigation strategies to lower CO_2 emissions and safeguard the planet's climate[88]. We must acknowledge the effects on the ecosystem and its inhabitants of the increased atmospheric concentrations of greenhouse gases [89]. Climate change and global warming are caused by an imbalance in the atmospheric gas concentrations, which has a devastating effect on Earth's fragile ecosystems and the natural processes that keep life on Earth going [90]. Alterations to the availability of water resources, changes in weather patterns, increased sea levels, polar ice cap melting, species extinction, and more are all consequences of climate change[91] . We must immediately begin to control and reduce emissions of anthropogenic greenhouse gases if we are to lessen the severity of these adverse effects [92]. Using modern carbon capture and storage technology, increasing energy efficiency, switching to renewable energy sources, and being mindful of land use are all ways to accomplish this goal[93].

Sustainable energy sources, which include effective controls and reductions of anthropogenic greenhouse gas emissions, are crucial for mitigating the negative impacts of climate change. Renewable energy investment, conservation and efficiency campaigns, low-carbon transportation advocacy, public education and awareness campaigns, and regulatory and policy incentives for sustainable energy use are all part of the solution [94]. By decreasing transportation-related greenhouse gas emissions, for instance, the transition to electric vehicles (EVs) can be pivotal[95]. Nevertheless, it is important to take into account both the positive and negative aspects associated with this shift The good news is that compared to cars fueled by gasoline, EVs consume far less energy, which means less pollution and less energy wasted[96]. Furthermore, electric vehicles are becoming more practical for longer trips due to improvements in battery technology that increase their storage capacity [97]. On the other hand, there is the potential for an increase in emissions during the production of EV batteries due to the high energy and resource requirements of this process[98]. There may need to be investments in infrastructure and energy generation to accommodate the shift to EVs because of the potential pressure on the electrical grid caused by the increased demand for electricity to power them [99]. Consequently, appropriate energy-efficiency measures to manage and reduce emissions of human greenhouse gases must also be put in place [100]. This involves advocating for and providing incentives for the use of energy-efficient infrastructure, including well-insulated buildings, energy-efficient lights and appliances, and environmentally friendly modes of transportation [101]. Modern methods of carbon capture and sequestration may also help bring down and manage emissions of man-made greenhouse gases [102]. Technology for carbon capture and sequestration entails removing carbon dioxide from the air by burying it or finding another way to keep it there for the long term[6]. Nevertheless, substantial funding for R&D and the launch of a large-scale demonstration project are necessary for the actualization of these technologies One interesting approach is membrane technology, which uses selective membranes to remove carbon dioxide gas from gas streams, including those generated by power plants that use fossil fuels [8]. Up to 90% of CO_2 emissions can be collected by using the selective membrane, which is specifically engineered to isolate CO_2 from the surrounding gas stream [9]. After comparing membrane technology to other carbon capture methods like adsorption or chemical absorption, it becomes clear that the former is more cost-effective and easier to maintain [10]. Policy and regulation that encourages the use of these technologies is essential for ensuring their efficacy in lowering emissions of greenhouse gases and for speeding up their deployment [11]. Greenhouse gas concentrations can be reduced through the implementation of responsible land use techniques such afforestation, reforestation, conservation agriculture, and sustainable forestry[103]. Deforestation is a major source of greenhouse gas emissions; avoiding it is possible through responsible land use practices[104]. Reduced usage of synthetic fertilizers, which produce the greenhouse gas nitrous oxide, is another way in which sustainable agricultural methods might lessen emissions [105].

Table 2: Climate Change Mitigation Strategies.

Strategy	Description	Benefits	Challenges	References
Energy Efficiency	Reducing energy consumption through improved technologies and practices.	Lower energy costs, reduced greenhouse gas emissions, increased resource efficiency.	Requires investments, behavioral changes, and potential job displacement.	[106]
Renewable Energy	Transitioning to energy sources like solar, wind, hydro, and geothermal.	Reduced greenhouse gas emissions, improved energy security, economic development.	Intermittency issues, land use concerns, and high initial investment costs.	[107]
Carbon Capture and Storage (CCS)	Capturing carbon dioxide from industrial processes and storing it underground.	Reduces emissions from existing fossil fuel infrastructure.	High cost, technological challenges, and potential leakage risks.	[108]
Afforestation and Reforestation	Planting trees to absorb carbon dioxide from the atmosphere.	Carbon sequestration, improved biodiversity, and watershed protection.	Land availability, cost, and potential for unintended consequences.	[109]
Sustainable Transportation	Promoting electric vehicles, public transportation, and active travel modes like cycling and walking.	Reduced greenhouse gas emissions, improved air quality, and reduced traffic congestion.	High initial costs for electric vehicles, infrastructure development needs, and potential for social equity challenges.	[110]
Sustainable Agriculture	Practices like agroforestry, conservation tillage, and organic farming that reduce emissions and improve soil	Reduced greenhouse gas emissions, improved food security, and enhanced biodiversity.	Requires changes in farming practices, potential for yield reductions, and market challenges.	[111]

	health.			
Carbon Pricing	Implementing mechanisms like carbon taxes or emissions trading schemes to create a financial incentive for reducing emissions.	Provides a clear price signal for emissions, promotes innovation, and raises revenue for climate action.	Potential for regressive impacts, administrative complexity, and political resistance.	[112]
Behavioral Change	Promoting individual actions like reducing energy consumption, consuming less meat, and choosing sustainable products.	Reduces overall emissions, promotes a more sustainable lifestyle, and raises awareness about climate change.	Requires significant public engagement, relies on individual action, and may not be sufficient to address climate change alone.	[113]
International Cooperation	Collaborative efforts between countries to address climate change through technology transfer, financial assistance, and policy alignment.	Promotes global equity, allows for sharing of resources and expertise, and increases the effectiveness of mitigation efforts.	Challenges in coordinating diverse interests, ensuring fairness, and enforcing agreements.	[114]

6. Solar Energy as a Solution

Wind farms, solar plants, biomass plants, and other renewable energy sources were accessible in rural regions. Solar energy systems, including solar thermal and photovoltaic (PV), are used in urban environments. In the early years, research into the utilization of solar energy in buildings was extremely technical, as also highlighted by N. Sánchez-Pantoja, R. Vidal, and M. Carmen (2021). The installation's energy efficiency and economic costs were the primary focus of attention. Renewable energy systems were the only basis for the challenge of developing energy models. Additionally, programs that prioritize the implementation of renewable energy sources on an urban scale, as well as storage energy systems, are indispensable for the successful mitigation of climate change, the enhancement of global energy performance in urban areas, and the establishment of more resilient cities. In this regard, the technical, environmental, social, economic, and political challenges of sustainable development were already being addressed through the use of terms such as "energy autonomy," "energy self-sufficiency," and "sustainable communities" [115].

A new solar planning strategy has been put into place by a number of European Union countries—Switzerland, Sweden, Germany, Austria, and Denmark—that proves it is possible to maximize solar energy usage while maintaining a site's architectural character and heritage. Furthermore, solar power is gaining popularity as a result of being named one of the most promising alternative energy sources in Malaysia. Thus, solar energy presented a chance for Malaysia's energy sector to foster green potential by reducing environmental impact. Solar power, which harnesses the sun's rays to create electricity, is an eco-friendly and comparatively inexpensive alternative to traditional power sources. [116]. M.R.M. Cruz et al. (2018) found that the EU has set a target to reduce GHG emissions from 1990 levels by 80–95% by 2050. Only by incorporating "green" energy sources, such as solar and wind, would this be possible. It is projected, in particular, that by 2050, wind and solar power will account for half of the EU's electrical generation. An increasing number of "carbon-free" energy supplies are being sought for [117].

In developing countries, conventional energy generation is currently the primary source of greenhouse gas emissions, accounting for approximately 40% of global primary energy and 40% of global electricity output. Consequently, fossil fuel power facilities release substantial quantities of harmful pollutants into the atmosphere, such as sulfur dioxide (SO_2), nitrogen oxides (NO_2), and carbon dioxide (CO_2). The primary cause of the rapid increase in CO_2 emissions in developing economies is the substantial increase in the use of conventional fuels, including coal, oil, and natural gas, to satisfy the rapidly increasing energy demand [118]. Consequently, solar energy is the most effective solution to energy poverty and can offer exceptional opportunities to reduce greenhouse gas emissions and indoor air pollution by substituting kerosene for illumination and firewood for kitchen use.

7. Case Studies

Solar energy has emerged as a critical solution for the mitigation of CO_2 emissions and the mitigation of climate change. Solar technologies contribute to the reduction of greenhouse gas emissions by directly converting sunlight into electricity or heat, thereby reducing dependence on fossil fuels. This review examines the successful implementation of solar energy systems worldwide, emphasizing their contribution to the reduction of CO_2 emissions.

- **Germany's Energiewende**

The Energiewende, Germany's ambitious energy transition plan, is designed to increase the proportion of renewable energy sources in the country's energy matrix. This strategy is significantly influenced by solar energy. By 2023, Germany had installed more than 50 GW of solar photovoltaic (PV) capacity. The Feed-in Tariff (FiT) program provided solar power producers with fixed payments as an incentive to install solar panels. The solar initiatives of Germany have resulted in a substantial decrease in CO_2 emissions. Germany decreased its greenhouse gas emissions by approximately 35% in comparison to 1990 levels between 2000 and 2020 (Federal Environment Agency, 2021) [119].

- **California's Solar Mandate**

California has implemented numerous policies to increase the use of solar energy, such as a state mandate that mandates the installation of solar panels in new residences. In 2020, California's Title 24 building standards mandate the installation of solar panels on new residential buildings that are three stories in height. The California Solar Initiative and net metering are among the incentives that the state provides. California's solar energy adoption is anticipated to decrease annual CO2 emissions by approximately 2.5 million tons by 2030 (California Energy Commission, 2022).[120]

- **China's Solar Energy Expansion**

China has emerged as the global champion in the deployment of solar energy, supported by the government and large-scale investments. China had installed more than 300 GW of solar PV capacity by 2023. The "Top Runner Program" has been implemented by the nation in order to expedite technological advancement and enhance efficiency. The installation of solar panels in China has made a substantial contribution to the reduction of its CO2 emissions. Approximately 2.3 billion tons of CO2 are mitigated annually in China by solar power (China National Energy Administration, 2023).[121]

- **India's Solar Mission**

The National Solar Mission of India is designed to increase the deployment of solar energy and decrease the country's reliance on coal-fired power. India established a goal of achieving 100 GW of solar capacity by 2022, which was subsequently increased to 280 GW by 2030. This endeavor is bolstered by initiatives such as the Jawaharlal Nehru National Solar Mission and the Solar Parks Scheme. India's solar mission is anticipated to decrease CO2 emissions by more than 1.5 billion tons by 2030 (Ministry of New and Renewable Energy, 2023).[122]

- **Morocco's Noor Solar Complex**

The Noor Solar Complex in Morocco is a critical element of the nation's renewable energy strategy and is one of the world's largest solar power facilities. The Noor complex, which comprises multiple phases, has a cumulative capacity of 580 MW. It generates electricity through the use of concentrated solar power (CSP). The Noor Solar Complex mitigates more than 760,000 kilograms of CO_2 emissions annually (Moroccan Agency for Solar Energy, 2023) [123].

8. Future Prospects

The efficiency and cost-effectiveness of solar energy have been substantially improved as a result of technological advancements. The development of tandem solar cells, multi-junction cells, and perovskite-based solar cells has resulted in an increase in power conversion efficiency, as a result of advancements in photovoltaic (PV) technology. These enhancements have decreased the cost per watt of solar energy and rendered it more competitive with conventional energy sources. Furthermore, the efficient storage and dispatch of solar energy have been facilitated by advancements in energy storage technologies, including lithium-ion batteries and flow batteries, while solar energy capture has been optimized through the implementation of solar tracking systems. The pervasive adoption of solar energy has been facilitated by these technological advancements, which have contributed to a more sustainable and cleaner energy future [124, 125].

Various policy measures can be implemented by governments to encourage the adoption of solar energy. Feed-in tariffs (FITs) make solar installations more financially viable by providing a fixed payment for each unit of solar electricity generated [126]. Net metering enables solar owners to sell surplus electricity to the grid, thereby decreasing their electricity expenditures [127]. Investment tax credits (ITCs) are among the tax incentives that provide advance cost reductions for solar installations

[128]. Administrative obstacles to solar adoption may be mitigated through simplified permitting procedures and diminished soft costs [129]. In addition, the advancement of solar technology can be expedited and costs can be reduced through public funding and research support [130].

Solar energy has the potential to substantially reduce the effects of global warming and its associated climate change. Research suggests that the rate of global temperature rise can be slowed and greenhouse gas emissions can be reduced by utilizing concentrated solar power (CSP) and photovoltaic (PV) technologies to harness solar energy. Research has demonstrated that the widespread implementation of solar energy can mitigate fossil fuel consumption, thereby reducing carbon dioxide emissions by billions of tons annually. Furthermore, solar energy can contribute to the enhancement of air quality by reducing particulate matter and other pollutants that are associated with the combustion of fossil fuels. Solar energy can contribute to the decarbonization of a variety of sectors, such as power generation, transportation, and heating, by generating pure, renewable electricity. This, in turn, can result in a more sustainable and healthier planet.

9. Conclusion

This comprehensive review has provided an in-depth analysis of the impact of CO2 emissions on global warming and the potential of solar energy as a mitigation strategy. It is well known that human-caused CO2 emissions are the main cause of global warming, which has dire ramifications for the environment, society, and economy. CO2 emissions are continuing to rise, as evidenced by historical and contemporary patterns, underscoring the critical need for efficient mitigation measures. There are serious threats to both human health and ecosystems as a result of the effects of global warming, which include rising sea levels, harsh weather, and biodiversity loss. Because of its availability, sustainability, and affordability, solar energy has become a viable solution to these problems. The viability and efficiency of solar energy in lowering CO2 emissions and accelerating the shift to clean energy have been shown through case studies. The future looks extremely bright for solar energy, as cost reductions and increased adoption are brought about by legislative incentives and technology improvements. However, more study and creativity will be needed to get over obstacles like scalability and intermittency. Overall, this analysis highlights the critical need for mitigation techniques and offers strong evidence of the catastrophic effects of CO_2 emissions on global warming. As a viable and affordable way to cut CO_2 emissions and solve the problems caused by global warming, solar energy has the potential to be a key component of this mitigation.

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