

Article

# Shifting towards renewable energy: A sustainable solution to pollution

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**Abstract:** The 21st century poses unprecedented challenges in addressing climate change and environmental degradation, largely driven by the reliance on fossil fuels such as coal, oil, and natural gas. These energy sources contribute significantly to greenhouse gas emissions and air pollution, resulting in detrimental effects on human health and ecosystems. This paper explores the urgent need to transition to renewable energy technologies—including solar, wind, hydroelectric, geothermal, and biomass—as a sustainable alternative. It highlights the economic viability of renewable energy, emphasizing job creation, reduced energy costs, and enhanced energy security. Effective policy frameworks are crucial for fostering the adoption of renewables and phasing out fossil fuel subsidies, thereby mitigating the adverse impacts of climate change and promoting public health. Ultimately, the integration of renewable energy into global energy portfolios is essential for achieving sustainable development and a cleaner future.

**Keywords:** renewable energy; climate change; sustainable development; fossil fuel alternatives

## 1. Introduction

The 21st century presents a crucial moment for humanity as we face the urgent need to tackle climate change and environmental degradation, largely caused by the heavy reliance on fossil fuels [1]. Coal, oil, and natural gas have historically been the mainstays of global energy production; however, their combustion releases harmful pollutants such as carbon dioxide (CO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and particulate matter (PM) [2]. These pollutants significantly contribute to global warming, climate change, and declining air quality, posing serious threats to human health and ecosystems [3]. In light of these environmental challenges, renewable energy technologies present a viable solution. Sources like solar, wind, hydroelectric, geothermal, and biomass utilize natural processes to produce electricity and heat with significantly lower environmental impacts and greenhouse gas emissions [4]. Transitioning from fossil fuels to renewable energy is not only an environmental necessity but also economically advantageous, supported by substantial empirical evidence and practical applications [5].

Renewable energy technologies provide numerous benefits over fossil fuels in terms of sustainability and environmental protection. For example, solar energy employs photovoltaic panels or concentrated solar power systems to convert sunlight into electricity, resulting in minimal environmental impact throughout its lifecycle [6]. Wind energy captures the kinetic energy of wind through turbines, generating clean electricity

without greenhouse gas emissions or pollutants during operation [7]. Hydroelectric power utilizes the gravitational force of flowing water, delivering a reliable energy source while maintaining a low carbon footprint [8]. Geothermal energy extracts natural heat from beneath the Earth's surface, providing a continuous energy supply with negligible greenhouse gas emissions [9]. Biomass energy employs organic materials like wood and agricultural residues to produce heat and electricity, serving as a renewable alternative to fossil fuels while potentially achieving carbon neutrality [10].

The feasibility and economic benefits of transitioning to renewable energy are becoming increasingly clear. A multitude of studies and real-world examples illustrate that investments in renewable energy infrastructure can lower energy costs, enhance energy security, and stimulate economic growth through job creation and technological advancement [11]. Regions that have adopted renewable energy strategies have reaped substantial rewards, including decreased reliance on imported fossil fuels and improved resilience to fluctuations in energy prices [12]. The declining costs associated with renewable energy technologies, alongside supportive policies and technological innovations, continue to propel the global transition toward a sustainable energy future [13].

Effective policy frameworks and international collaboration are essential for accelerating the adoption of renewable energy technologies and phasing out fossil fuel subsidies. Initiatives such as carbon pricing, feed-in tariffs, renewable portfolio standards, and tax incentives are crucial for promoting investments in renewable energy and fostering an environment conducive to sustainable development [14]. By prioritizing the deployment of renewable energy and creating a supportive regulatory framework, global communities can mitigate the adverse effects of climate change, enhance public health, and protect ecosystems for future generations [15].

## **2. Methodology**

This study employs a mixed-methods approach to examine the role of renewable energy technologies in mitigating climate change and environmental degradation. It begins with a systematic literature review of peer-reviewed articles and reports from 2010 to 2023, synthesizing findings on the effectiveness of various renewable sources. Quantitative analysis assesses the cost-effectiveness and economic benefits of these technologies, utilizing data on installation and operational costs, job creation, and technological advancements, with comparative statistical methods. Qualitative case studies from diverse regions highlight implementation challenges and successes through semi-structured interviews with stakeholders and site observations. A comparative regional analysis explores variations in the renewable energy transition across developed and developing countries, integrating all findings to provide comprehensive insights and policy recommendations for enhancing renewable energy adoption.

## **3. Current pollution crisis**

The burning of fossil fuels is a major source of air pollution, as outlined in **Table 1**.

In urban and industrial areas, emissions from vehicles, power plants, and factories release a complex mix of pollutants into the air, including sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), volatile organic compounds (VOCs), and particulate matter (PM) [16]. These pollutants degrade local air quality and contribute to regional and global smog, acid rain, and ground-level ozone, severely impacting human health [17].

**Table 1.** Impact of conventional energy.

Source of Energy	Description	Impact	Effect on Plants and Animals
Coal	A fossil fuel formed from ancient plant matter, burned for electricity and heat.	High greenhouse gas emissions Air pollution leading to health issues	Acid rain harming forests and aquatic ecosystems
Oil	A liquid fossil fuel used for transportation and heating.	Significant carbon emissions Oil spills causing habitat destruction	Oil spills harming marine life Disruption of food chains
Natural Gas	A fossil fuel primarily composed of methane, used for heating and electricity generation.	Lower emissions than coal and oil, but still significant	Methane leaks contribute to climate change Potential harm to wildlife
Nuclear	Energy produced through nuclear fission; non-renewable due to uranium supply.	Risk of radioactive waste and accidents	Low greenhouse gas emissions during operation Habitat impact from mining uranium
Peat	An accumulation of decayed vegetation, used as a fuel source in some regions.	Emits significant CO <sub>2</sub> when burned	Loss of biodiversity in peatland ecosystems

Exposure to these pollutants is linked to serious health problems, including respiratory diseases like asthma and chronic obstructive pulmonary disease (COPD), cardiovascular issues, and an elevated risk of premature death [17]. Vulnerable groups, including children, the elderly, and those with pre-existing health conditions, face heightened risks [18]. Moreover, the deposition of these pollutants into water bodies and soil leads to environmental harm, biodiversity loss, and disruption of ecosystems [19]. For instance, acid rain adversely affects aquatic ecosystems and damages forests and agricultural crops.

Addressing the pollution crisis requires a comprehensive strategy that integrates the deployment of renewable energy, energy efficiency measures, sustainable transportation systems, and advanced pollution control technologies [20]. Transitioning to renewable energy sources such as solar, wind, hydroelectric, geothermal, and biomass can significantly cut emissions of greenhouse gases and air pollutants [21]. These technologies utilize natural processes to generate electricity and heat with minimal environmental consequences, contributing to climate change mitigation [22,23].

Additionally, policy frameworks that incentivize investments in renewable energy, promote cleaner technologies, and eliminate fossil fuel subsidies are vital. Mechanisms like carbon pricing, feed-in tariffs, and emissions trading systems are critical for hastening the shift to a low-carbon economy and ensuring sustainable development [24]. International collaboration and commitment to these objectives are essential for meeting global targets related to greenhouse gas emissions and air quality improvements [25].

## **4. Renewable energy technologies**

Renewable energy technologies encompass a range of methods for energy generation and use:

- **Solar Energy:** Solar technologies, such as photovoltaic (PV) cells, directly convert sunlight into electricity, while concentrated solar power (CSP) systems use mirrors or lenses to focus solar energy for electricity or heat production [26].
- **Wind Energy:** Wind turbines capture wind's kinetic energy to generate electricity. Onshore and offshore installations are increasingly common, contributing to sustainable energy production [27].
- **Hydroelectric Power:** Hydroelectric dams and run-of-river systems harness flowing water to generate electricity, providing a consistent power supply with minimal greenhouse gas emissions [28].
- **Geothermal Energy:** Geothermal power plants extract heat from beneath the Earth's surface, generating electricity and providing direct heating and cooling. This form of energy is considered reliable due to its consistent availability [29].
- **Biomass Energy:** Biomass includes organic materials such as wood, agricultural residues, and organic waste. It can be converted into biofuels or directly burned for heat and electricity, serving as a renewable alternative to fossil fuels [30].

Each renewable technology presents unique advantages and challenges influenced by geographic location, resource availability, and technological maturity. Advances in technology and economies of scale have significantly lowered the costs of renewable energy generation, enhancing their competitiveness against traditional fossil fuels in many regions [31].

Globally, renewable energy deployment has been rising steadily, driven by environmental concerns, energy security needs, and economic advantages. Solar and wind power have particularly experienced rapid growth due to declining costs and supportive government policies [32]. Hydroelectric power continues to play a significant role in global electricity generation, especially in areas with abundant water resources [33]. Geothermal projects are expanding in regions with suitable geological conditions, offering sustainable energy solutions in both developed and developing nations [34]. Biomass energy, while more localized, is vital for decentralized energy production and rural development [35].

Diversifying energy sources through renewable technologies is essential for addressing climate change, reducing reliance on fossil fuels, and promoting sustainable global development. Ongoing investments in research, development, and infrastructure are crucial for advancing renewable energy deployment and realizing a clean energy future.

## **5. Role of renewable energy in pollution mitigation**

Renewable energy is essential in combating pollution and minimizing greenhouse gas emissions worldwide:

**Greenhouse Gas Reductions:** By displacing fossil fuel-based electricity generation, renewable sources significantly reduce carbon dioxide (CO<sub>2</sub>) and other greenhouse gas emissions. This reduction is critical for addressing climate change and meeting international climate goals [36].

**Air Quality Improvement:** The shift to renewable energy technologies leads to notable enhancements in air quality. Reducing emissions of pollutants like sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), particulate matter (PM), and volatile organic compounds (VOCs) helps lessen respiratory and cardiovascular diseases linked to poor air quality [37].

**Water and Soil Protection:** Unlike fossil fuel extraction and combustion, renewable energy technologies have minimal direct effects on water resources and soil quality. This characteristic is vital for preserving ecosystems, maintaining biodiversity, and supporting sustainable land use practices [38].

The environmental and public health benefits of renewable energy are evidenced by various case studies. For instance, Germany's Energiewende initiative has successfully reduced the country's carbon footprint while boosting economic growth and enhancing energy security through significant investments in renewable infrastructure [39]. Likewise, Costa Rica has made remarkable progress toward achieving nearly 100% renewable electricity generation, demonstrating the feasibility of ambitious renewable energy targets in smaller and developing countries [40].

Integrating renewable energy into national energy portfolios not only diversifies energy sources but also strengthens energy resilience and decreases dependence on imported fossil fuels. Nations prioritizing renewable energy deployment gain enhanced energy security, reduced environmental impacts, and improved public health outcomes [10].

The broad adoption of renewable energy technologies is crucial for achieving sustainable development goals, combating climate change, and protecting public health. Continued investments in renewable energy research, development, and deployment are essential for facilitating the global transition to a low-carbon economy and ensuring a cleaner, more resilient future for generations to come.

## **6. Economic and environmental benefits**

Transitioning to renewable energy brings substantial economic and environmental benefits at local, national, and global levels:

**Job Creation:** The renewable energy sector is a significant source of employment, providing opportunities for skilled workers in areas like manufacturing, installation, maintenance, and research and development. Expanding renewable energy infrastructure drives economic growth and job creation in both urban and rural settings [11].

**Cost Competitiveness:** Advances in renewable energy technologies, alongside economies of scale and decreasing production costs, have made these energy sources increasingly competitive with traditional fossil fuels. Solar and wind energy, in particular, have reached grid parity in many regions, making them appealing investments for utilities, businesses, and consumers [12].

**Energy Security:** Renewable energy diversifies energy sources and reduces dependence on imported fossil fuels, enhancing energy security and resilience to geopolitical instability and price volatility. Countries investing in renewable energy infrastructure gain greater energy independence and reduced vulnerability to supply disruptions [13].

**Environmental Conservation:** Renewable energy technologies generally have less environmental impact compared to fossil fuel extraction and use. By cutting greenhouse gas emissions, air and water pollution, and habitat destruction, renewable energy aids in biodiversity conservation and ecosystem resilience [14].

**Public Health Benefits:** Adopting renewable energy improves public health outcomes by lowering exposure to air pollutants and alleviating the health impacts of climate change on vulnerable populations. Communities with cleaner air quality and reduced pollution levels often see lower rates of respiratory diseases, cardiovascular issues, and premature mortality [15].

These advantages underscore the multifaceted benefits of transitioning to renewable energy, not only in terms of economic prosperity and energy security but also in fostering environmental sustainability and public health on a global scale.

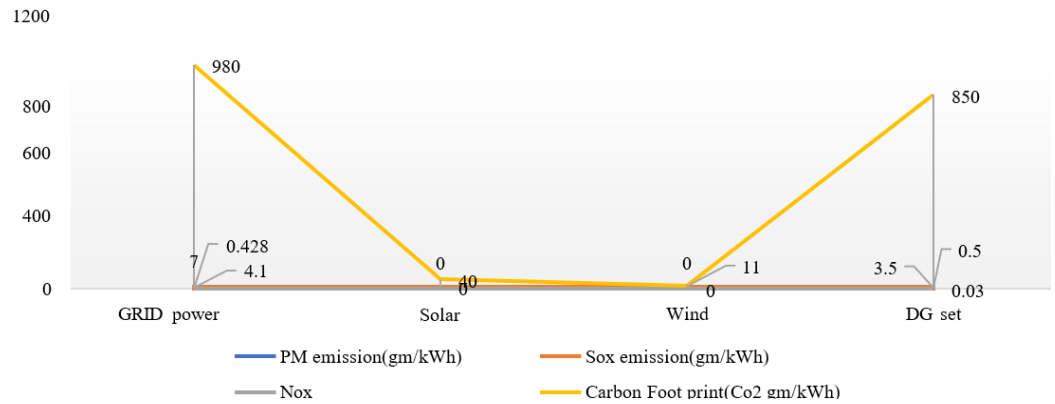
## **7. Environmental impact of different energy sources**

The main environmental impact of thermal power plants is air pollution through different polluting gases and particulate matter emitted from the burning of fossil fuels in boilers. Additionally, fly ash collected from electrostatic precipitators (ESPs) and bed ash collected from the boiler firing bed contribute to environmental impacts. Boilers emit a variety of polluting gases and particulate matter through stacks. In addition to this, bed ashes and fly ashes are also generated in solid fuel-fired boilers along with particulate matter and pollutant gases. The main gaseous pollutants include carbon dioxide (CO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), sulfur dioxide (SO<sub>2</sub>), carbon monoxide (CO), formaldehyde, polynuclear aromatic hydrocarbons (PAHs), lead, hydrogen chloride (HCl), cadmium, mercury, dioxins/furans, and other toxic chemicals). These pollutants have varying impacts on the environment and human health. Major environmental impacts include climate change, acid rain, and the greenhouse effect. In terms of safety, thermal power plants present significant risks. There have been numerous instances worldwide of boiler explosions, resulting in substantial loss of life and property damage. The main environmental impact of DG power is air pollution through different polluting gases and particulate matters emitted from the burning of diesel in diesel engine. This is having a very similar kind of pollution impact as automobiles.

DG sets emit a variety of polluting gases and very less quantity of particulate matters through stacks. The main gaseous pollutants are Carbon dioxide (CO<sub>2</sub>), Nitrogen oxides (NO<sub>x</sub>), Sulfur dioxide (SO<sub>2</sub>), Carbon monoxide (CO), etc. These pollutants have different impacts on environment and on human health. The major impact on environment is climate change, acid rain and greenhouse effect etc. When we think about the Safety impact of DG sets there is no any significant risk during power plant operations.

Solar power generation system is having very low environmental impact. Total carbon foot print is verylow compared to conventional power generation system. Health and safety impact are also low compared to conventional power generation system.

Similarly, the wind power generation system is also having very low environmental impact like solar power generation system. Health and safety impact are also low compared to conventional power generation systems. Different types of particulate matter and gaseous emission is given in **Table 2**. The environmental impact also given in **Figure 1** to get better idea by visual comparison where GRID power is having highest environmental impact and the solar power is having lowest impact.



**Figure 1.** Environmental impact of different energy sources.

**Table 2.** Environmental impact of different energy generation systems.

Fuel	PM emission(gm/kWh)	Sox emission(gm/kWh)	NOx Emission(gm/kWh)	Carbon Foot print (CO <sub>2</sub> gm/kWh)	Impact index
GRID power (Coal)	4.1	7	0.428	980	4
Solar	0	0	0	40	1
Wind	0	0	0	11	1
DG set	0.03	3.5	0.5	850	2

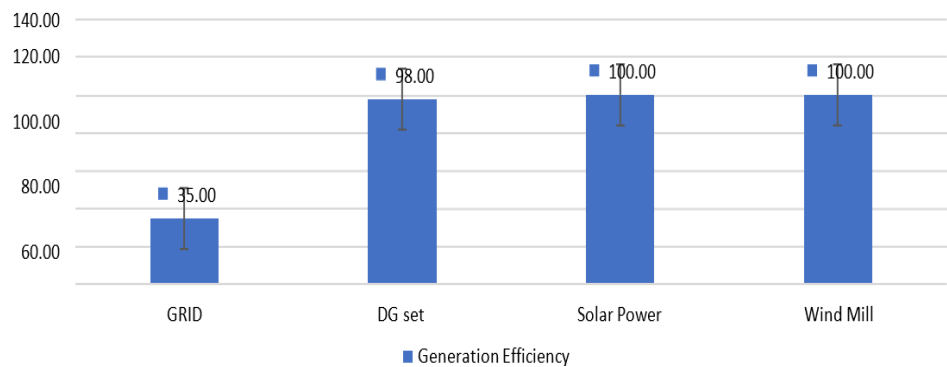
### 8. Generation efficiency of different energy sources

If we keep aside the factory efficiency which will be same for any type of energy supply the main efficiency to be considered that is losses from input to output. When we consider the GRID power which is mainly generated from the solar power plants there are many losses which to be discussed. Generation losses, transmission losses and distribution losses.

If we keep aside the factory efficiency which will be same for any type of energy supply the main efficiency to be considered that is losses from input to output. When we consider the DG power which is mainly generated from the combustion of diesel there are many losses which to be discussed. Mainly Generation losses is there apart from that transmission losses and distribution losses are very negligible because the power supposed to be generated in the same premises of factory where the DG power is intended

to be use.

The efficiency of solar power generation currently ranges from approximately 10% to 20% [40]. Advancements in technology are continually being made, and it is anticipated that the efficiency of solar power panels will improve further in the near future. In contrast, wind power generation typically achieves efficiencies between 20% and 40% [41]. The power generation efficiency is also expected to improve further like solar power generation system with new developments in this field. Though solar power generation efficiency is lower but it is considered as 100% as it has no any physical input supplied by the user. Different energy sources having different generation efficiency is given in **Figure 2**.



**Figure 2.** Generation efficiency of different energy sources.

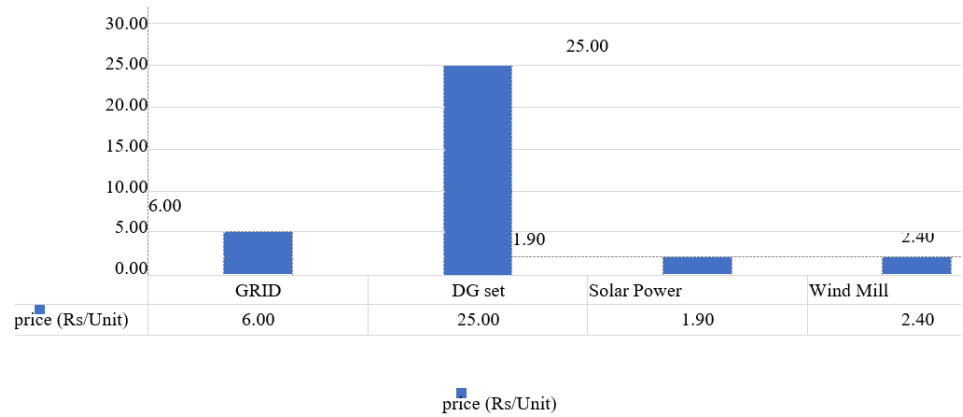
## 9. Economic impact of different energy sources

The power is being generated by burning the fossil fuel, transmitted and finally distributed to the point of use. The cost of electricity is around 6 Rupees per unit. The power is being generated by burning the Diesel hence the cost of generation is much higher compared to other power generation system. The cost of electricity generated from DG set is around 24 to 30 Rupees per unit in India now a days.

Since solar power requires no input material for its operation and converts solar energy into electrical energy, the power generation cost is very low which is on account of its installation and operation cost only.

Like solar power generation wind power requires no input material for its operation and it convertswind energy into electrical energy, the power generation cost is very low which is on account of its installation and operation cost only. Economic impact of different energy sources is given in **Figure 3**.

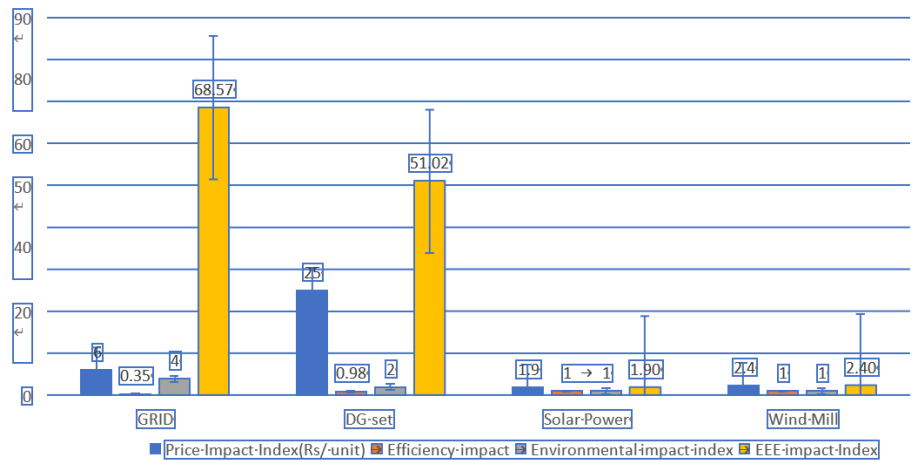




**Figure 3.** Economic impact of different energy sources.

### 10. EEE impact factor analysis of different energy sources

When we combine all the impacts i.e., environmental impact, generation efficiency impact and economic factor impact that is known as EEE impact EEE factor, as introduced by Jena et al. [42] according to which the study was conducted for evaluation of available alternate energy sources. It is calculated and given in **Table 3** and the values are plotted in a graph given in **Figure 4**.



**Figure 4.** EEE impact factor energy source.

**Table 3.** EEE impact of different energy sources.

Fuel	GRID	DG set	Solar Power	Wind Mill
Price Impact Index (Rs/unit)	6.00	25.00	1.90	2.40
Efficiency impact	0.35	0.98	1	1
Environmental impact index	4	2	1	1
EEE impact Index	24.00	50.00	1.90	2.40

## 11. Observation and discussion

The comparison of conventional and renewable energy sources reveals significant differences in environmental impact, generation efficiency, and economic viability. Conventional energy sources, such as coal, oil, and natural gas, are major contributors to greenhouse gas emissions, air pollution, and habitat destruction, as shown in **Table 1**. These impacts include high carbon emissions, acid rain, and toxic spills that adversely affect both plants and animals. In contrast, renewable energy technologies—like solar, wind, and hydroelectric power—exhibit markedly lower environmental footprints. They not only reduce greenhouse gas emissions but also improve air quality by eliminating harmful pollutants. The observed data indicate that while coal generates substantial emissions, solar and wind energy produce negligible to zero emissions during operation.

The efficiency of energy generation also varies widely among these sources. While fossil fuel power plants suffer from significant generation and transmission losses, solar and wind energy systems, despite having lower maximum efficiencies (10%–20% for solar and 20%–40% for wind), are inherently more efficient due to the absence of fuel input costs. Economically, renewable sources present compelling advantages: the cost of electricity from solar and wind is significantly lower than from diesel generators and conventional fossil fuels, as highlighted in **Figure 3**. This transition to renewable energy not only promises reduced costs but also fosters job creation in growing sectors.

Overall, the findings support the argument for a shift toward renewable energy as a means to combat climate change, enhance energy security, and promote sustainable development. The Environmental, Economic, and Efficiency (EEE) impact analysis in **Table 3** underscores that renewable sources like solar and wind yield the most favorable EEE indices, reinforcing their potential as critical components in the global energy transition. Continued investment and innovation in these technologies are essential for maximizing their benefits and achieving a sustainable energy future.

## 12. Policy recommendations

Robust policy frameworks and regulatory mechanisms are crucial for facilitating the transition to renewable energy and meeting sustainable development goals, as summarized in **Table 4**:

- **Renewable Energy Targets:** Governments should set ambitious renewable energy deployment targets, backed by clear timelines, incentives, and regulatory frameworks. Renewable portfolio standards, feed-in tariffs, and competitive procurement processes can drive investments in renewable energy projects and facilitate market integration [16].
- **Carbon Pricing:** Implementing carbon pricing mechanisms, such as carbon taxes or emissions trading systems, incentivizes emissions reductions and encourages investment in low-carbon technologies. Revenue generated can be reinvested into renewable energy research, development, and infrastructure, further accelerating the transition to a low-carbon economy [17].

- **Fossil Fuel Subsidy Reform:** Eliminating subsidies for fossil fuels and reallocating financial resources toward renewable energy investments can create a level playing field and foster market competitiveness. Governments should prioritize the removal of environmentally harmful subsidies and adopt transparent fiscal policies that support sustainable energy transitions [18].
- **Research and Innovation:** Ongoing investments in renewable energy research, development, and innovation are vital for advancing technological breakthroughs, enhancing energy efficiency, and reducing renewable energy generation costs. Public-private partnerships and international collaboration can expedite the commercialization and deployment of innovative renewable technologies [19].
- **Capacity Building and Education:** Fostering renewable energy literacy and capacity building among policymakers, businesses, and communities encourages informed decision-making and boosts public support for sustainable energy transitions. Educational initiatives, training programs, and knowledge-sharing platforms can empower stakeholders to actively participate in shaping a clean energy future [20].

These policy measures are essential for creating an enabling environment for renewable energy adoption, fostering innovation, and driving sustainable development across economies worldwide.

**Table 4.** Summary of policy impact.

<b>Policy Recommendation</b>	<b>Description</b>	<b>Potential Impact</b>
Emissions Regulations	Implement strict emissions standards for coal, oil, and natural gas industries.	Reduction in greenhouse gas emissions Improved air quality and public health
Incentives for Clean Technology	Provide tax credits and subsidies for technologies that reduce emissions from conventional energy.	Encouragement of innovation and investment Transition towards cleaner energy solutions
Transition Plans for Coal Workers	Develop retraining programs for workers in declining coal industries.	Support for affected communities Facilitation of workforce transition to renewable sectors
Investment in Carbon Capture and Storage (CCS)	Fund research and deployment of CCS technologies in fossil fuel plants.	Mitigation of carbon emissions from conventional energy Extended operational life of existing energy infrastructure
Energy Efficiency Standards	Establish and enforce energy efficiency standards for conventional energy production.	Reduction in overall energy consumption Lower energy costs for consumers
Public Awareness Campaigns	Launch initiatives to inform the public about the environmental impacts of conventional energy.	Increased public support for cleaner energy policies Greater accountability for energy producers
Diversification of Energy Sources	Encourage a mix of energy sources to reduce reliance on any single conventional source.	Enhanced energy security Resilience to market fluctuations

### 13. Conclusion

The transition from conventional fossil fuels to renewable energy sources is not merely an environmental necessity but a strategic imperative for economic growth and public health. The current pollution crisis underscores the urgent need for action, as the health impacts of air pollutants and greenhouse gas emissions continue to threaten vulnerable populations and ecosystems. Renewable energy technologies present a viable pathway to mitigate these impacts, providing cleaner alternatives that enhance air quality and promote sustainable development.

The implementation of robust policy measures—such as emissions regulations, incentives for clean technologies, and the establishment of renewable energy targets—will be pivotal in accelerating this transition. Additionally, fostering public awareness and education will strengthen community support for sustainable practices. As countries and regions increasingly invest in renewable energy infrastructure, they will not only achieve substantial environmental benefits but also bolster their economic resilience and energy independence.

Moving forward, a coordinated global effort is essential to ensure that the shift towards renewable energy is inclusive and equitable, paving the way for a sustainable and resilient future for all.

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