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Renewable Energy Adoption for Reducing Urban Pollution

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Abstract

Urban pollution has become a critical environmental and health concern. The rapid urbanization and increasing energy demands have led to a significant rise in urban pollution, posing severe threats to environmental sustainability and human health. This study examines the role of renewable energy adoption in mitigating urban pollution, based on a structured survey conducted among various stakeholders, including energy experts, city officials, and general residents. The survey covers awareness, technological acceptance, policy satisfaction, and future trends. The findings indicate a strong interest in renewable energy but highlight concerns about government support, cost, and technological limitations. A comprehensive review of existing case study is conducted to analyze the effectiveness of renewable energy technologies such as solar, wind, and bioenergy. The study suggests implementing policy improvements, offering financial incentives, and providing public education to enhance adoption. This study investigates the potential of renewable energy in addressing urban pollution through a structured survey that targeted diverse stakeholders, including energy experts, city administrators, policymakers, and everyday urban residents. The survey explored four key dimensions: awareness of renewable technologies, acceptance of new innovations, satisfaction with current government policies, and expectations regarding future energy trends. Results show that while there is a strong and growing interest in transitioning toward renewable sources, such as solar, wind, and bioenergy, several barriers hinder widespread adoption. These include high initial costs, limited technological infrastructure, and a perceived lack of consistent governmental support and incentives. To supplement survey findings, the study also conducts a comprehensive review of existing case studies that document real-world applications of renewable technologies in urban environments. Evidence suggests that cities investing in renewable solutions not only reduce their carbon footprint but also experience co-benefits such as improved public health, job creation, and enhanced energy security. Based on these insights, the study recommends targeted policy reforms, stronger financial incentives, and public education campaigns to raise awareness and promote behavioral change. Together, these measures can accelerate renewable energy adoption and play a critical role in mitigating urban pollution.

Keywords: Renewable energy adoption, urban pollution reduction, sustainable energy, public awareness, technological acceptance, environmental impacts, financial considerations, policy and incentives

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INTRODUCTION

The rapid growth of cities has resulted in higher energy consumption, primarily driven by fossil fuels, which contributes to air pollution and greenhouse gas emissions. Urban pollution, driven particularly from vehicular emissions, industrial activities, and energy production has become one of the leading causes of health and environmental issues facing modern society. The increasing levels of urban pollution, especially in densely populated regions, demand immediate interventions. Urbanization and industrial activities have significantly contributed to air pollution, leading to severe health and environmental consequences.

Renewable energy sources, such as solar, wind, and bioenergy, present viable solutions for reducing urban air pollution by replacing fossil-fuel-based generation. Transitioning to renewable energy, such as solar, wind, and bioenergy, can help to reduce pollution. This chapter focuses on the role of renewable energy in mitigating air pollution in urban areas, with a particular emphasis on how adopting these technologies can contribute to sustainable urban development.

OBJECTIVES

The status of urban pollution in urban centers is alarming, with many cities worldwide experiencing deteriorating air quality levels. The status of air pollution in Delhi, Gujarat, and Bihar is alarming [1]. The status of air pollution in Punjab's urban centers is concerning, particularly during the postharvest season in the late autumn and winter. Major urban areas, such as Ludhiana (AQI 134), Amritsar (AQI 151), and Jalandhar (AQI 132), have high levels of air pollution, significantly affecting public health and the environment.

Contributing factors to air pollution in urban centers are industrial activities, agricultural burning, vehicular emissions, and domestic pollution.

- Renewable energy technologies which help to reduce pollution are solar energy, wind energy, biomass energy, hydro energy, and biogas energy. These technologies play a vital role in reducing urban pollution, like reduced greenhouse gas emissions, improved air quality, enhanced energy security, decreased air pollutants (PM, Nox, SO_2), and the main benefits are economic benefits, job creation, reduced fuel costs, etc.
- The barriers and opportunities for the widespread adoption of renewable energy in urban areas are:
    - *High upfront costs:* Renewable energy projects, especially solar and wind farms, require large upfront capital investments, where many investors perceive these projects as risky due to uncertain returns.
    - *Infrastructure limitations:* Without proper transmission infrastructure, renewable energy potential remains underutilized.

Public sector budget constraints: governments with tight budgets may prioritize short-term economic needs over long-term renewable energy investments.

Policy recommendations for encouraging the adoption of renewable energy to combat urban pollution is:

- Increase renewable energy targets.
- Invest in infrastructure development.
- Promote public awareness and education.
- Encourage private sector investment.
- Monitor progress and adjust strategies.
- Expand the green financing option.
- Encourage public-private partnerships.

SCOPE OF STUDY

Air pollution levels across India remain a significant concern, with many regions experiencing poor air quality. The assessment of pollution levels in various urban regions of India focuses on air pollution. Punjab, an agricultural and industrial hub, faces significant environmental challenges due to industrial emissions, vehicular pollution, agricultural practices like stubble burning and urbanization [2].

- Air pollution levels are very poor in most regions of the world. The national air quality index categorizes air quality into six levels: good, satisfactory, moderately polluted, poor, very poor, and severe. These categories are determined based on concentrations of key pollutants like: PM, Nox, Sox, CO, and VOCs.
- Recent data indicates that India's many different states' overall air quality index stands at 136, which is classified as "poor".

- An investigation into renewable energy technologies – especially solar, wind, and biomass energy highlights the potential of these sources in addressing the global energy demand while reducing carbon emissions. Renewable energy technologies, like solar, wind, and biomass, are essential in transitioning to low-carbon future [3]. Each technology has its own benefits, their integration in energy systems coupled with advancements in storage and grid management will drive the decarbonization of global energy systems. Uses of solar panels save water and reduce costs.
- Despite the numerous benefits of renewable energy, its widespread adoption faces significant economic and policy-related barriers. These obstacles affect the improvement of technologies like solar, wind, and bioenergy and hinder the transition toward a cleaner, sustainable energy future. Some important economic and policy barriers are given as follows:
    - High initial costs.
    - Grid infrastructure and reliability.
    - Energy storage costs and challenges.
    - Lack of land and resources.
    - Lack of technology.
    - Public and political resistance.
    - Subsidies for fossil fuels.

Here are some inspiring success stories of renewable energy adoption worldwide:

- *India's Renewable energy expansion:* The country built the Bhadla solar park, which is one of the largest solar farms in the world.
- *China's solar power revolution:* China is the world's largest producer of solar energy. It has built the Tengger desert solar park, which covers 1200 square kilometers.
- *Kusum scheme:* solar for farmers (India).
- Gujarat's solar and wind hybrid projects.
- India is rapidly transforming its energy sector with its solar, wind, and hybrid projects. The government is also focused on green hydrogen projects, energy storage solutions, etc.

METHODOLOGY

Data Collection

The study uses both primary and secondary data sources. Primary data includes survey responses from stakeholders, including renewable energy adopters and the public. Secondary data includes research papers, industrial reports, and publications.

Technology Assessments

The study evaluates various renewable energy sources and technologies, including:

- Solar panels for electricity production and help in agricultural field.
- Solar panels are used for street lighting and public infrastructure, and water purification.
- Wind turbines are used for desalination and water purification.
- Wind turbines for producing electricity.
- Biomass energy is used in heating and cooking.
- Biomass power plants generate electricity from organic waste.

RESULT AND DISCUSSION

Demographic Information

The survey respondents belong to diverse age groups, occupations, and regions. The survey included a mix of energy experts, city officials, and general residents, primarily from urban and suburban areas [4]. The majority were aged 18–40, indicating a younger demographic interested in energy transition.

- *Survey Outcome:* Out of 106 respondents, 48.1% are young respondents who are students. About 49.1% of respondents belong to the suburban area, 38.7% from the urban area and 12.2% from the rural area (Figure 1).

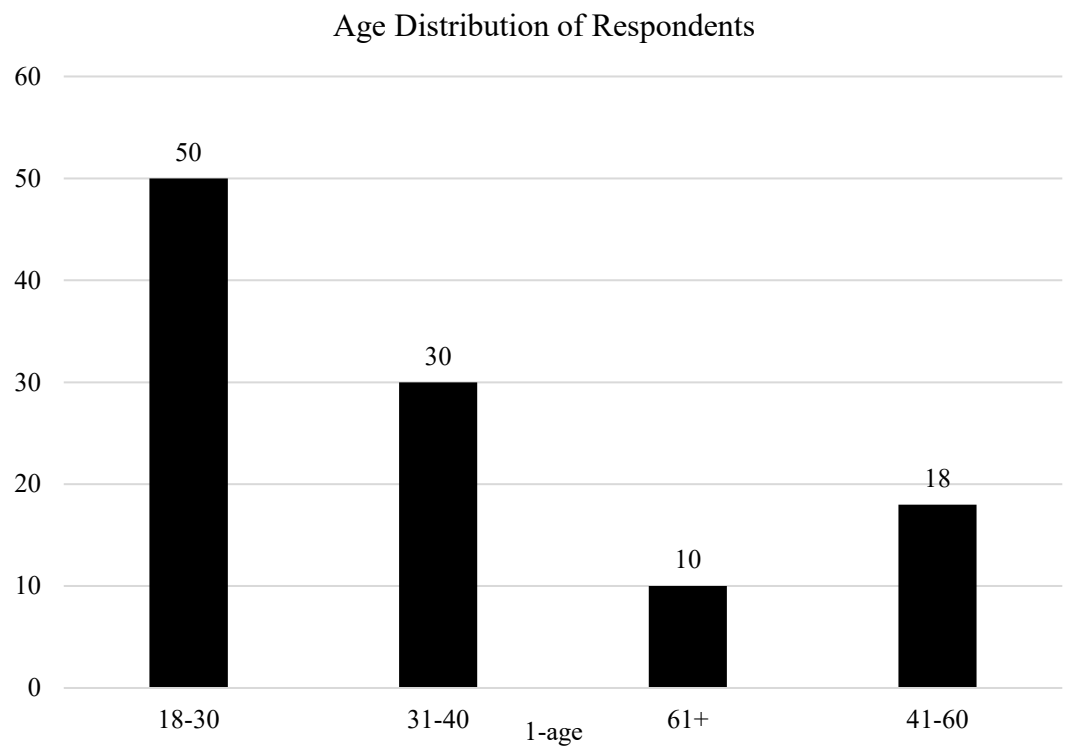

Figure 1. Age distribution of respondents.

Awareness of Urban Pollution

A significant portion of respondents rated their awareness of urban pollution in their area as poor to good. The key challenges identified are that only 45% of people are slightly aware of the role of fossil fuels in contributing to urban pollution. These responses highlight the need for more educational initiatives [5].

- *Survey Outcome:* Nearly 45.3% of respondents rated their awareness level as slightly aware, while above 30.2% moderate level to good awareness of the role of fossil fuels in contributing to urban pollution. About 45% respondents rated as good and 20–30% respondents rated the poor to neutral air quality in their area (Figures 2 and 3).

Renewable Energy Adoption

A significant portion of respondents rated their knowledge to renewable energy adoption as good. Solar energy was the most recognized renewable source, followed by bioenergy and wind energy. Despite moderate awareness, actual adoption rates remained low due to cost concerns, technical uncertainties, and lack of clear government incentives [6, 7].

- *Survey Outcomes:* About 50% respondents are slightly aware, and 41% are moderately aware of renewable energy technologies. Solar energy and wind energy are considered more effective compared to bioenergy.

Government and Policy Support

Many respondents expressed dissatisfaction with government support due to inadequate financial incentives and weak policy enforcement. Many respondents suggested policy improvements included subsidies, stricter pollution control laws, and green projects.

- *Survey Outcome:* Above 20% of respondents are dissatisfied, and 50% respondents are satisfied with government policies to renewable energy adoption. More respondents suggested prioritizing the incentives for adopting renewable energy and prioritizing the regulations on reducing fossil fuel usage.

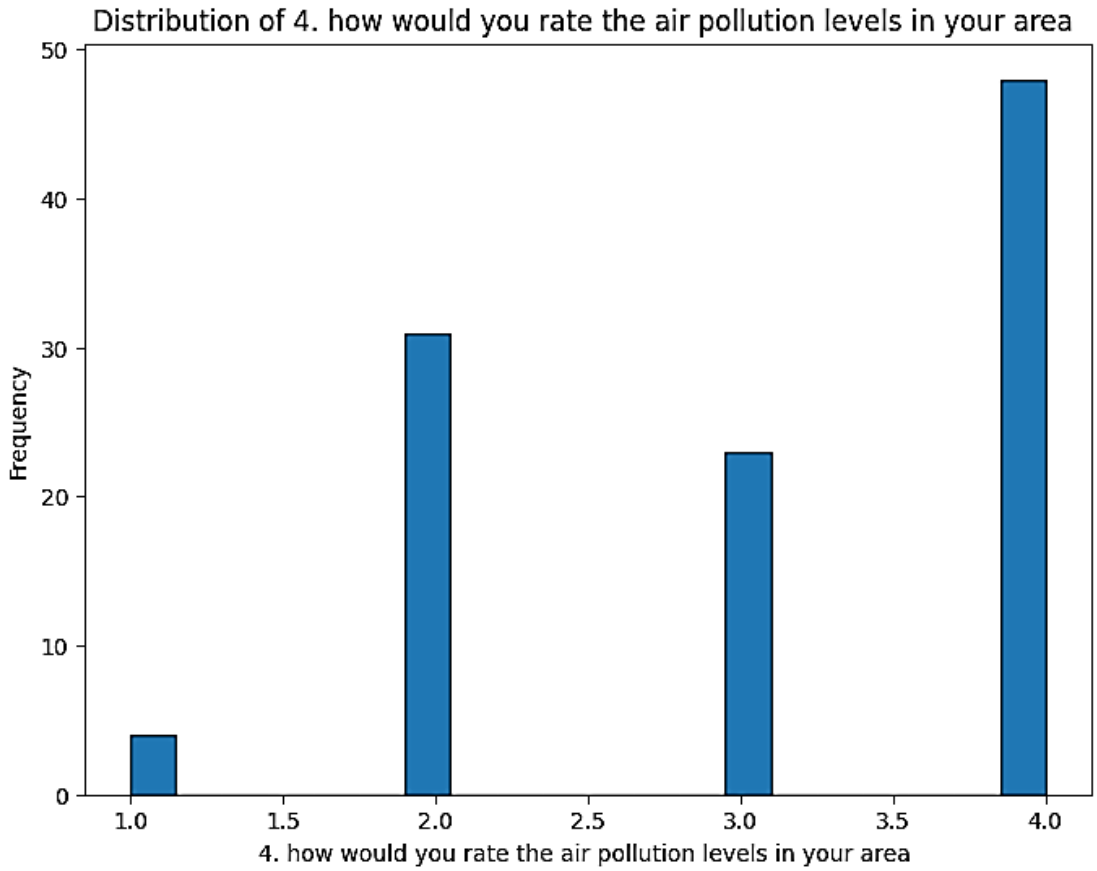

Figure 2. Distribution of 4. How would you rate the air pollution levels in your area.

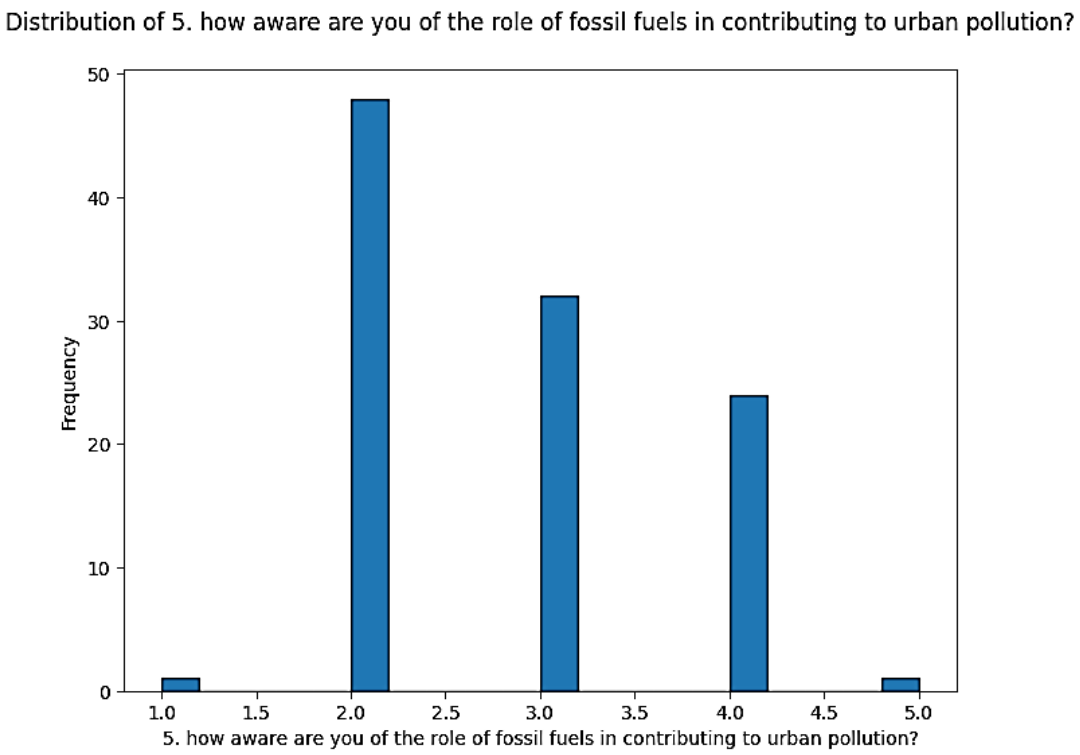

Figure 3. Distribution of 5. How aware are you of the role of fossil fuels in contributing to urban pollution?

Personal Actions and Attitudes

Renewable energy sources, such as solar, wind, and bioenergy, offer sustainable alternatives, so personal commitment is equally essential in transitioning to renewable energy.

- *Survey Outcome:* About 54% respondents are moderately likely to adopt renewable energy and 21.7% are slightly likely, and 22.6% likely to adopt renewable energy technologies. Around 50% respondents are rated to support, 24.5% are neutral and 21.7% respondents are opposed to believe that urban centers prioritize renewable energy adoption to reduce pollution.

FUTURE ENGAGEMENT

A significant portion of respondents expressed interest in future renewable energy engagement, is investing in renewable energy projects and adopting energy-efficient technologies. Future engagement levels were also strongly correlated with education and awareness campaigns.

- *Survey Outcome:* about 50% of respondents are moderately concerned, 30% are slightly concerned, and 16% respondents are concerned about the long-term impact of pollution on urban sustainability. 54% of respondents are moderately willing, and 29.8% are slightly willing to participate in the programs focused on renewable energy adoption. Nearly 10% well-educated respondents are willing to do it [8].

Technological Innovation and Precision Agriculture Solutions

A significant portion of respondents show their interest in technological innovation of renewable energy technologies, which helps in various fields to save the environment, low costs, water supplies, and electricity production. It also plays a big role in agriculture, like using motor solar panels, to supply water to the crops.

- *Survey Outcome:* about 40–50% of respondents are slightly to moderately familiar with AI-based nutrient management, 30–50% of respondents are slightly to moderately familiar with GPS mapping for crop monitoring, 35–55% of respondents are moderately familiar with IoT-based soil sensors, and 54% respondents are slightly aware of drone-based monitoring.

Environmental Impact Perception

Most respondents believed that renewable energy reduces air pollution and mitigates climate change. Many respondents recognized that solar and wind energy decrease dependence on fossil fuels, reducing greenhouse gas emissions and managing agricultural waste.

- *Survey Outcome:* about 37% respondents are rated moderately important, and almost 50% respondents are rated as slightly important to reduce urban pollution for public health. Nearly 41% of respondents are rated to disagree, and 34% agree to believe that renewable energy adoption can significantly improve air quality in urban areas [9].

Financial Considerations

The upfront costs of solar panels, wind turbines, and energy storage system were a major barrier despite long-term savings, so subsidies, low-interest loans, and tax reductions can improve and encourage residential and commercial adoption of renewable energy. It should be developing community-based renewable energy programs to reduce financial barriers.

- *Survey Outcome:* almost 64% of the respondents rate a lack of financial incentives is a big barrier to adopt renewable energy, and 25% say uncertainty of return on investment is a big barrier. About 40–45% of respondents are slightly to moderately willing to invest in renewable energy solutions if financial incentives were provided.

Community Engagement

Respondents believed that community-based initiatives could lower costs and improve accessibility to renewable energy and shared solar and wind projects were seen as potential solutions for urban communities. Respondents are also showing interest in participating if local governments were provided financial support and organizational guidance.

- *Survey Outcome:* About 51% respondents are slightly engaged and 39% respondents are moderately engaged in community discussions, and 40–47% of respondents are willing to participate in community programs focused on renewable energy awareness.

Technological Acceptance

Many respondents expressed happiness about the reliability of solar panels and wind energy, electrical vehicles, smart meters, AI-based monitoring technologies, green hydrogen projects, etc. Barriers to accepting these technologies are a lack of knowledge and financial support.

- *Survey Outcome:* nearly 53% of respondents are slightly confident, and 31% of respondents are moderately confident in the effectiveness of renewable energy technologies. Many respondents are concerned that maintenance costs and intermittent energy supply as compared to technological advancements, are reliable for renewable energy technologies.

Comparative Awareness

Many respondents overestimated the reliability of fossil fuels while underestimating renewable energy improvements in efficiency and reliability. Respondents showed more awareness of fossil fuels than renewable energy sources, while solar energy was well-recognized, knowledge about wind and bioenergy was significantly lower.

- *Survey Outcome:* almost 43% of respondents are considered to have the same knowledge to others, and 42% respondents rated themselves as less knowledgeable in their community. This is a lack of education. More respondents give the same rating to social media and news articles, but some more educated people rely on academic research for information about renewable energy technologies.

Impact of Education

Respondents with higher levels of education have greater awareness of renewable energy technologies and their benefits, but respondents with less education or limited education have less knowledge and are less familiar with this concept.

- *Survey Outcome:* almost 40–50% respondents are slightly to moderately believe that education is very important to promote renewable energy adoption to reduce urban pollution. Around 44% of the respondents have participated in such programs related to renewable energy, and most of the respondents have not even participated in the programs.

Policy Awareness

Policy awareness is a key factor for influencing renewable energy adoption. Many respondents remain unaware of financial incentives, regulatory mandates, and long-term energy policies. The lack of policy awareness is limiting their participation in the transition to clean energy.

- *Survey Outcomes:* about 54% of the respondents are only slightly aware about local policies, and 30% of the respondents are moderately aware, which means very few people have good knowledge about local policies. Nearly 54% of the respondents rated it as slightly effective and 32% of respondents are moderately effective believe that existing policies are in promoting renewable energy adoption.

FUTURE TECHNOLOGIES TRENDS

Technological advancements play a vital role in promoting the adoption of renewable energy. It improves efficiency, reliability, and affordability of renewable energy sources. Innovations in solar, wind, and bioenergy and energy storage systems are crucial for enabling a large-scale shift away from fossil fuels [10].

- *Survey Outcome:* advanced solar technologies, like solar panels, building-integrated PV, and smart grid infrastructure, hold the most promising technologies to promote renewable energy adoption as compared to offshore wind energy and energy storage solutions.

Future Prospects

The future of renewable energy in reducing urban pollution looks promising with advancements in technology and policy support. It will continue the waste management to reduce urban pollution.

- *Smart cities and energy efficiency:* smart grids, smart meters, and energy-efficient buildings.
- *Green hydrogen is a clean fuel:* expansion of green hydrogen production.
- *Government policies and carbon pricing:* implementation of urban low-emission zones.
- *AI and Big data in pollution control:* AI-driven energy forecasting and use of digital twins.
- *Expansion of solar and wind energy and electrification of transport:* growth in electrical vehicles and increased efficiency in solar panels and wind turbines. These trends will help cities lead to cleaner and more sustainable urban environments.

CONCLUSIONS

Renewable energy adoption is widely recognized as a solution to reduce urban pollution. Renewable energy technologies are used in a wide range. It is very impactful to clean the air and water. It saves time, money, and gives a pollution-free infrastructure of society, energy storage solutions, etc.

RECOMMENDATIONS

- Implement education programs for younger populations to improve awareness of renewable energy adoption for reducing urban pollution.
- Increase community engagement efforts to enhance sustainable energy technologies adoption.
- Address barriers to adopting renewable energy technologies through public awareness campaigns and policy incentives.
- Use policy interventions and financial support to improve technological advancements.

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