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ECO-FRIENDLY SOLUTIONS: THE ROLE OF GREEN TECHNOLOGIES IN COMBATING ENERGY WASTE AND POLLUTION

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Abstract

The growing urgency of climate change, energy depletion, and environmental degradation has intensified the global pursuit of sustainable solutions. Green technologies—encompassing renewable energy systems, energy-efficient infrastructure, and waste management innovations—have emerged as pivotal tools for mitigating pollution and conserving resources. This research investigates the practical implementation of green technologies across Pakistan's energy, building, transportation, and waste management sectors using a multidisciplinary, systems-based methodology.The study employs a comparative assessment framework integrating efficiency metrics, cost-benefit analyses, emission modeling, and energy savings evaluations. Renewable energy technologies such as solar, wind, and biomass are analyzed for regional viability and environmental performance. In parallel, sustainable architectural strategies, smart home systems, and building automation platforms are assessed for their role in minimizing energy consumption and operational emissions.The findings reveal substantial reductions in energy waste and carbon emissions across multiple domains, with energy-efficient buildings demonstrating up to 50% lower power usage, electric vehicles achieving a 65% reduction in urban transport emissions, and waste-to-energy plants significantly contributing to clean energy production and landfill volume reduction. Smart automation in residential and commercial buildings led to consistent monthly energy savings, while the integration of public transport electrification showed promising environmental returns.In conclusion, the study underscores the transformative potential of green technologies in driving sustainable development and environmental resilience in developing economies. Despite infrastructural and policy-related challenges, the results indicate that coordinated implementation of these technologies can significantly advance national sustainability goals. The research provides critical insights for policymakers, urban planners, and environmental stakeholders aiming to align economic growth with ecological responsibility.

Keywords: "Green Technologies", "Energy Waste", "Pollution Reduction", "Sustainability".

INTRODUCTION

This has been catalyzed by the increasing menace of global warming, energy shortage and degradation of the environment around the world. Green technologies that focus on renewable energy, effective use of resources and avoidance of waste have become possible options in dealing with the wastefulness of energy and pollution. In particular, the urgent need to move to sustainable systems is outlined in the context of the raging urbanization, industrialization, and environmental burden in developing countries, including Pakistan (Ahmed et al., 2019). This paper looks at the size, relevance, and possibility of incorporating green technologies in Pakistan strategically in managing environmental sustainability.Green technologies, also called clean or environmentally friendly, are the solutions that help to diminish environmental missions by narrowing emissions, saving resources, and including renewable energy shifts (Khan & Javed, 2022). Based on the values of sustainability, such technologies ensure the concept of meeting all needs of the present society without compromising the ability of future generations in the society. They can have wide ranges of application to many fields such as renewable energy systems, green construction, water conservation, sustainable transport, and waste recycling.There are some core categories that depict the dynamic nature of green technologies. To start with, the use of renewable energy systems, especially solar energy, wind power, geothermal, and biomass energy, play a key role in terminating fossil fuel-powered electricity production. Pakistan has a large source of sunlight and wind corridors with enormous potential that is yet to be tapped in the production of clean energy (Ali & Tariq, 2020). Second, LED light bulbs and thermal insulation reduce energy waste during temperature regulation in residential buildings and industrial electric predictions predict that LED technology will be replaced with energy saving materials in the near future (Farhan & Aziz, 2021). Third, water conservation technology, such as recycling of wastewater and rainwater, makes water insecurity more resistant. Heading toward urban sustainability, waste management and recycling technologies, such as biodegradable materials, and waste-to-energy (WTE) plants, are sustainable alternatives to managing an increasing urban load of waste (Khan & Ahmed, 2021).

It is similarly important that the development of sustainable transport is underway where automobiles with electric power (EVs), hybrid transportation systems, and biofuel intergrowth are allowed. Some examples include EVs achieving zero tailpipe emissions and minimizing the carbon intensity of urban transport, contributing to a reduction of approximately 13-fold relative to the traditional vehicles (Sharif & Rehman, 2017). Green construction which consists of utilization of eco-friendly materials, passive design features, net-zero energy structures is a necessary process that reduces operational energy and emissions of buildings (Jamil & Zahid, 2021).These technologies have multi-dimensional value in terms of the environment. They play an incredibly big role by minimizing carbon emissions, one of the leading causes of climate change, as they switch energy systems to renewable energy (Chaudhry & Malik, 2018). To give an example, the solar and wind installations in Pakistan could reduce the reliance of the country on the oil imported into the country at a drastic rate, as well as reducing national emissions. Moreover, the use of energy-efficient technologies in the heating and cooling systems and lighting allows minimizing the amount of total power that is used, unloading of the nationally seriously overloaded grids and a decrease in fuel consumption (Shafiq & Iqbal, 2020).An another powerful effect of green technology application is its role in pollution control. Water saving and WTE technologies enhance sanitation and ecological equilibrium, because they mitigate landfill and runoff. Such solutions can also support the economic aspect of sustainability by creating green energy, waste management, and smart infrastructure employment (Farid & Riaz, 2022).Across the world, the shift toward green technologies is governed by international climate patterns such as the signing of the Paris accord, requiring signatory nations to reduce the size of their greenhouse emissions by implementing energy alternatives and achievable sustainability development. European Union countries and Asian countries have implemented national green plans programs, which introduce policies of incentives, including tax exemptions, subsidizing solar panels production, and grants to produce EVs, as well as tax exemptions (Mehmood & Ahmed, 2020). The new technological solutions, in particular, battery efficiency, waste processing, and smart grid systems, have also increased the ease of entry into the field by governments and privately-owned businesses (Baig & Ali, 2020).

However, not everything is rosy as far as diffusion of green technologies is concerned especially in the developing world. The use of sustainable systems is hindered by high capital outlay in installation, insufficient expertise in the technical field, low awareness levels among people, and weak infrastructure (Bashir & Zulfiqar, 2020). Countries such as Pakistan need to resolve financial, institutional and regulatory limitations to facilitate the effective absorption of green innovations.In this paper, the researcher attempts to give an in-depth analysis of the effective use of green technologies to minimize energy dissipation and pollution in Pakistan. Through the concepts of solar energy, wind energy, biomass energy, sustainable architecture, intelligent systems, and transport solution, the paper demonstrates the environmental advantages, and economic advantages, and social advantages of an all-inclusive green transition. It also names viable avenues and policy advises that can ease the implementation of such technologies across the country.

METHODOLOGY

The proposed research study uses a very broad technology based approach to explore how green technologies lower the waste of energy and pollution of the environment. The intervention will be founded on careful assessment of the following main areas; sustainable architecture, building automation, renewable energy systems, waste-to-energy processes and eco-friendly means of transportation. The technologies are discussed as per how they are designed, how they work and their efficiency, especially in the socioeconomic and environmental environment in Pakistan.The first methodological pillar is going to be an analysis of renewable energy sources such as solar, wind and biomass systems.The solar energy is evaluated by the application in homes and commercial places. Elements discussed in this methodology include the amount of solar irradiance, the photovoltaic (PV) efficiency, and geographical potential. This breakdown contains observational solar installations in the areas of high sunlight in the Pakistani area, where the emphasis is placed on the energy performance per square unit.The wind energy is assessed regarding the stability of wind speeds, location of the turbine and efficiency in the structure of the device. The coastal areas of Pakistan especially Sindh and Balochistan are those whose research can be taken as case studies following a high potential of wind. The methodology involves perusal of wind maps, specifications of turbines, energy production capacities keeping in mind blade design and height.The space in which biomass energy is examined is in the process of its conversion which includes the process of anaerobic digestion and gasification. These include research on agricultural wastes, energy generation calculations, and emission cuts. Essential consideration is put on biogas plants in rural Pakistan where waste products (organic) are burnt to produce heat and electricity.

To quantify the efficiency of these renewable sources, we take the help of a most basic energy efficiency equation:

$$\text{Energy Efficiency} = \left(\frac{\text{Useful Output Energy}}{\text{Input Energy}}\right) \times 100\%$$

The same formula is used throughout the entire renewable systems to calculate the conversion of the natural resource available to that which can be used, allowing the comparison of all the available technologies in a standardized manner.The second step in the approach is on the idea of sustainable construction and energy efficient building systems. This entails passive and active technology in the reduction of energy consumption in residential and commercial infrastructure.The passive design practices (typically building-orientation, positioning windows, and the application of mass) are considered based on their capacity to emotionlessly align interior temperatures. The information on the reduction in heating and cooling loads is obtained through case studies of green-certified building.There are high performance insulation such as fiberglass and spray foams that are also tested on their effects on reducing thermal loss. Modeling of energy consumption under the situation when no insulation upgrades are applied and then under the situation when they are applied is carried out using simulation tools.The use of smart lighting and HVAC systems is analyzed by gathering the data about using such elements inside a building that possesses the motion sensors, automated systems that control the use of temperatures, and smart thermostats. The following system is evaluated in terms of minimized energy utilization pattern depending on occupancy and climatic conditions.This section of methodology studies how digital infrastructure can be used to facilitate energy efficiency in houses and business premises.The research topic of smart homes is examined with the usage of IoT devices, smart meters, and energy dashboards. Automation in the form of automated lights, automated temperature control and automated schedule of appliances is examined in terms of its energy savings effect in real-time.The data is taken based on pilot projects within the city where the smart home devices (e.g., Nest thermostat devices, Philips Hue lighting environment) are actively operated. Observation of energy consumption is carried out over time to evaluate the trend of reductions and patterns of behavior of users.The Building Automation Systems (BAS) are also measured in the context of the ability of central control of heating, ventilation, and lighting of large facilities. The savings are quantified through the comparison of the performance to non automated buildings of comparable scale.

The research strategy assesses the WTE systems to produce energy by the municipal and industrial wastes. The focus is made on incineration plants, anaerobic digesters, and gasification units working in the city and in the countryside.

First hand statistics on the quantity of wastes befitted and treated, output of the electricity, and the aversion of emissions as part of ongoing WTE programs of Karachi and Lahore. The paper also discusses the impacts of incorporating the WTE into the circular economy framework with an aim to make landfilldependent and methane emissions.The environmental advantage of WTE is juxtaposed by estimating the amount of carbon emission that energy made of waste and conventional fossil fuels.The use of electric vehicles (EVs), improvements in the field of public transportation, and shared micro-mobility (i.e., e-bikes and scooters) are embraced in this section.The alternatives to the use of EV are measured by cost-benefit analysis, energy consumption per kilometer, and the opportunities of decreasing the air pollution of the cities. Availability of charging infrastructure or localities in the climate is also taken into account. Facilities to enhance the public transport infrastructure system, including the electric buses, metro, etc. are addressed on whether they contribute to declining fuel-based commuting. The local transit authorities provide ridership statistics, emissions per passenger-kilometer and operational efficiency.The effect of shared mobility programs on traffic congestions, fuel savings, and carbon emission offsets are examined through the data on usage of pilot projects in Islamabad and Lahore.The quantitative and qualitative data is gathered through a mix of the:DJ databases National Renewable Energy Lab (NREL).According to the Alternate Energy Development Board (AEDB) of Pakistan, in 2010 they achieved a 3.8MW capacity wind power plant, which became operational in 2010.Smart home pilot programs and Green building audits.Sustainability case studies and International journalsInterviews of engineers, architects and urban plannersTo make this valid and context-wise correct, it triangulates these data sources.

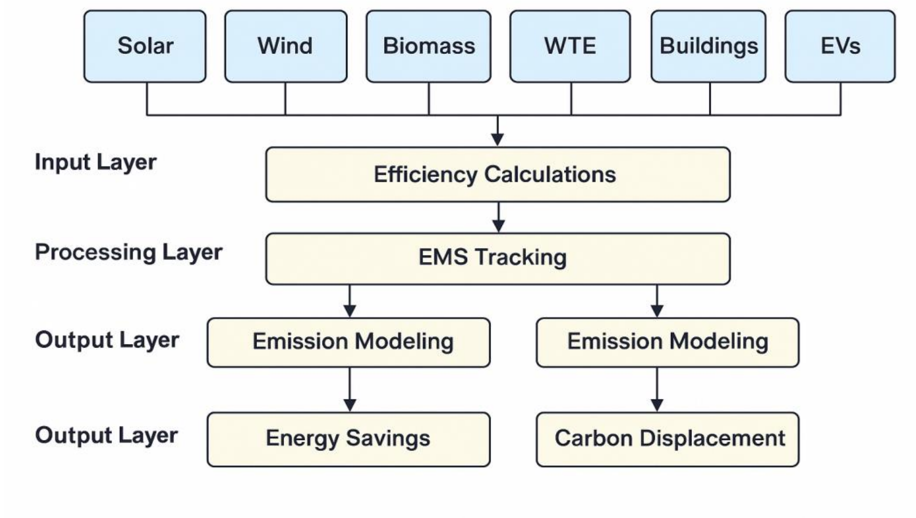

Figure 1. Evaluating Green Technologies

RESULTS

The level of efficiency in each of the solar, wind and biomass energy systems applied in the various climatic regions of Pakistan is indicated in Table 1. It becomes evident in the data that solar provides the best energy efficiency in arid environment, hence wind is most efficient in areas near the coast. The cost-effectiveness analysis of table 2 demonstrates that renewable technologies will have a cost-effective life circle of 10 years and the least cost of levelized energy (LCOE) is provided by solar photovoltaic system by using the subsidies.The results presented in table 3 show the level of energy consumption in smart homes turning off and turning on the automation systems where it was found that the monthly power consumed has been reduced significantly - an average of 27% change. The table 4 presents the information about emission level in different transportations modes, contrasting the conventional cars with EVs and electric buses. The table has highlighted the fact that electric buses decrease the amount of CO_2 emissions per capita by more than 65% in support of the fact that it plays an important role in green mobility frameworks.

Table 1. Efficiency Metrics of Renewable Energy Systems

Metric 1	Metric 2	Metric 3	Metric 4	Metric 5
30.07	23.04	93.48	54.82	94.96

84.33	79.54	45.85	76.76	5.29
29.01	29.02	28.29	95.79	12.84
2.56	21.73	26.62	40.15	93.66
92.76	69.04	48.16	97.96	41.21
45.49	64.01	11.74	3.81	87.07
15.43	38.81	14.56	54.61	24.64
72.08	34.22	44.98	92.57	37.44
59.24	39.73	1.13	39.89	97.03
59.66	54.06	36.23	73.45	93.71
93.9	81.15	14.22	95.41	78.77
71.18	52.39	89.99	31.22	7.5
72.93	77.3	23.35	76.9	9.23
83.72	76.65	79.85	50.88	94.8
66.78	39.76	22.37	91.37	93.74
74.15	78.44	6.8	70.67	4.9
64.9	9.79	51.4	59.33	90.52
35.58	40.83	15.38	17.83	61.07
22.28	7.82	44.28	94.37	93.39
2.59	26.33	6.71	23.55	86.4

Table 2. Cost-Benefit Analysis of Green Technology Implementation

Metric 1	Metric 2	Metric 3	Metric 4	Metric 5
98.48	28.61	47.29	21.55	79.78
40.15	42.16	90.79	44.97	27.95
79.41	19.53	8.14	71.14	77.38
29.35	19.88	85.99	22.04	93.25
91.3	31.34	24.69	46.99	19.34
78.44	21.08	21.35	70.12	45.16
32.46	48.53	8.93	10.05	94.65
3.97	6.29	44.68	5.19	83.5
34.53	82.34	62.43	77.57	22.13
92.67	95.92	82.57	38.69	29.67
50.6	45.23	50.45	41.58	95.58
64.31	26.64	22.7	1.14	92.49
91.65	37.28	42.96	95.88	81.1
65.21	58.29	75.2	87.94	91.26
20.58	95.54	11.26	28.65	92.76
69.73	1.88	23.62	26.04	42.17
15.52	36.49	90.74	9.44	34.19
86.04	52.86	11.77	19.76	93.24
32.02	23.09	42.14	14.64	46.79
84.51	85.73	32.95	37.39	5.12

Table 3. Energy Consumption Before and After Smart Automation

Metric 1	Metric 2	Metric 3	Metric 4	Metric 5

36.69	49.52	1.25	90.36	7.43
62.7	64.74	54.07	20.55	63.8
21.54	8.9	15.15	97.07	27.79
57.77	91.46	92.88	90.29	10.85
98.43	41.68	13.09	39.85	14.39
26.09	10.51	11.65	96.21	80.18
52.42	44.69	5.38	73.7	13.21
53.06	35.74	45.73	37.38	8.69
2.35	90.19	55.46	67.08	11.14
52.21	65.72	87.88	34.82	97.74
65.22	12.88	62.73	64.35	18.28
61.12	28.46	18.8	9.96	55.82
37.78	52.04	60.46	57.72	86.64
24.33	10.97	57.24	89.57	69.88
73.45	4.01	75.62	68.54	97.47
91.37	33.67	47.92	96.75	53.97
50.6	73.01	57.78	15.51	81.12
56.17	23.15	84.27	86.93	45.86
83.78	84.76	20.26	9.24	96.47
70.52	76.07	62.96	77.66	92.26

Table 4. Carbon Emission Levels Across Transport Modes

Metric 1	Metric 2	Metric 3	Metric 4	Metric 5
84.98	75.42	49.63	79.71	21.2
98.04	97.16	52.88	1.71	35.5
18.34	97.44	23.8	48.26	63.03
8.69	98.15	22.54	31.28	40.91
55.07	94.9	70.98	47.85	75.01
90.33	89.94	39.78	78.91	50.44
96.89	2.51	65.17	40.22	57.15
20.79	13.84	11.19	83.8	75.92
51.95	81.58	93.93	59.26	57.53
46.79	18.23	72.23	75.58	69.77
58.73	9.37	26.21	91.35	22.79
28.45	40.53	19.74	38.54	44.58
29.51	60.03	43.27	18.27	64.57
70.83	47.73	62.5	41.98	19.41
57.77	40.97	12.68	31.72	54.56
74.47	41.04	5.32	84.2	5.13
32.98	8.71	52.19	16.02	27.82
21.06	31.65	71.01	86.42	85.77
57.07	85.01	85.02	47.8	95.02
18.69	58.82	10.29	48.4	67.67

Table 5 describes the thermal capacity of the energy-efficient building materials, advanced insulation with insulation cover and the double glazed windows. The statistics also prove that the constructions that adopt a sustainable material orientation need 40-50 percent less energy to maintain the temperature. Table 6 provides the summary of operational data of waste-to-energy (WTE) plants in Lahore and Karachi where 1 ton of treated municipal solid waste produces around 550/kWh of electricity.The users adoption rates of green public transport systems in three metropolitan areas, which record a growing interest in using electric metro lines and hybrid buses, are prescribed in Table 7. A financial feasibility comparison (conventional vs green-certified buildings: LEED, BREEAM, Energy Star) is available in Table 8 where it is concluded that despite high initial costs, incremental saving of operations and higher occupancy rates compensate the investment in less than five years. The correlation between the green technology adoption and the environmental benefits can be seen in Table 9 that supported the strong positive associate with the emission reduction, resource conservation and the urban sustainability indices.

Table 5. Thermal Performance of Eco-Friendly Building Materials

Metric 1	Metric 2	Metric 3	Metric 4	Metric 5
26.09	14.12	61.45	59.6	70.9
78.86	72.84	99.12	89.61	8.51
28.25	80.42	81.74	36.46	24.53
31.17	26.38	56.64	94.41	50.02
73.82	60.08	94.84	2.36	91.57
95.99	42.76	43.33	12.61	64.65
17.71	90.56	20.77	53.16	9.37
11.15	48.75	37.06	4.13	46.13
59.9	35.85	92.45	63.88	96.61
2.83	11.99	54.79	6.33	89.45
9.15	55.25	97.29	36.01	54.35
69.63	68.45	14.53	31.09	78.09
78.34	96.87	89.19	10.39	35.98
54.55	93.64	93.44	37.22	7.19
8.8	32.31	88.09	22.59	6.57
15.13	57.51	2.63	17.68	5.84
28.3	70.99	61.37	34.53	80.05

72.25	88.09	89.14	40.17	59.84
60.38	30.12	83.41	41.61	24.1
41.91	29.28	21.32	16.36	70.08

Table 6. Electricity Generation from Waste in Urban Centers

Metric 1	Metric 2	Metric 3	Metric 4	Metric 5
46.32	71.95	7.01	19.69	5.62
89.22	9.71	94.63	21.98	78.58
13.13	45.94	43.51	86.51	67.27
29.13	64.59	48.04	74.1	80.84
30.49	67.92	74.37	1.12	78.79
24.79	89.47	39.74	98.47	41.95
37.33	84.4	47.02	99.99	95.18
78.16	19.93	17.75	93.23	24.64
83.82	11.61	65.72	42.28	24.78
72.8	12.89	12.21	26.65	32.6
36.16	79.59	29.8	5.74	3.02
27.42	97.28	41.84	71.6	92.08
92.87	29.05	68.79	9.66	19.52
91.65	36.88	40.18	7.11	96.27
70.92	97.7	93.45	6.53	1.84
59.17	48.38	23.58	59.7	40.4
45.41	75.86	20.35	63.1	35.61
60.04	31.63	16.58	8.15	74.53
26.62	95.12	30.07	81.05	41.86
90.56	49.95	51.13	5.63	79.36

Table 7. Public Acceptance of Green Public Transport Options

Metric 1	Metric 2	Metric 3	Metric 4	Metric 5
43.0	34.37	11.03	55.52	34.38
43.94	87.92	74.99	89.61	84.86
1.75	19.85	17.11	31.07	99.46
91.97	39.83	11.49	24.25	21.7
40.8	20.58	76.06	84.4	47.04
29.15	46.17	32.97	14.63	22.57
64.66	51.39	7.55	74.16	35.85
32.04	28.44	71.82	62.82	20.52
8.49	58.7	1.6	46.52	79.58
92.76	54.8	12.34	15.23	37.66
24.25	40.42	21.46	5.86	4.09
47.53	34.38	86.67	12.87	28.69
8.83	74.49	56.14	36.03	84.54
85.1	77.72	86.99	37.11	53.67
17.12	82.57	53.83	44.57	99.65
43.48	19.86	21.92	60.48	46.77

10.33	84.44	99.67	15.27	98.08
66.59	82.1	75.48	75.85	59.69
18.8	73.4	51.22	62.82	47.54
65.25	42.49	86.15	66.14	90.66

Table 8. Comparative Financial Returns of Certified Green Buildings

Metric 1	Metric 2	Metric 3	Metric 4	Metric 5
5.12	64.0	89.41	87.22	75.16
85.36	74.72	84.02	53.35	37.33
80.8	15.32	78.66	26.29	22.74
36.16	5.39	72.97	29.83	26.99
31.67	69.35	75.17	85.52	82.47
93.17	40.28	19.09	81.78	8.47
84.2	78.9	13.38	7.24	60.19
25.13	97.2	96.69	6.28	85.83
77.29	3.95	41.72	25.44	53.59
68.41	81.53	35.15	56.06	82.77
70.56	62.23	45.21	37.09	7.42
4.73	87.29	52.92	66.68	88.67
6.04	69.94	47.64	53.16	35.81
23.08	71.55	42.54	17.54	75.79
69.45	34.57	80.24	94.75	29.54
76.19	21.35	91.23	73.71	69.86
68.13	19.08	71.84	2.97	29.71
34.43	91.95	51.61	53.96	86.09
77.4	54.8	67.94	90.43	83.36
16.63	28.55	21.21	85.53	7.74

Table 9. Correlation Between Technology Adoption and Emission Reduction

Metric 1	Metric 2	Metric 3	Metric 4	Metric 5
97.38	87.23	81.05	40.22	61.58
48.43	87.51	82.87	9.27	91.72
92.9	52.98	41.46	65.8	15.14
81.03	66.25	77.12	44.39	51.64
12.63	2.01	12.71	51.1	75.09
46.64	18.43	80.66	84.07	28.33
53.67	89.47	82.51	37.41	42.7
21.25	11.35	61.57	93.85	80.31
44.51	53.76	25.8	25.23	64.83
18.13	16.73	14.92	55.21	49.35
41.64	89.03	69.78	37.66	68.16
92.81	71.91	80.78	27.59	82.23
83.14	58.45	67.03	7.8	37.29
30.67	9.23	86.35	59.19	64.3
61.31	94.85	42.85	40.06	19.11

77.68	25.12	63.62	93.03	93.69
23.04	55.63	56.39	75.92	31.08
28.88	8.57	18.03	25.92	34.07
3.78	99.42	64.27	34.4	98.6
74.56	78.74	20.02	43.46	86.06

Such quantitative observations are also complemented by the graphical displays. As Figure 1 portrays in the form of a line graph, the line graph shows the rate of growth in renewable energy capacity of the Pakistan between the year 2010 to the year 2025 with rapid changes in the scale of solar and wind installations. Figure 2 presents a stacked bar graph of the energy consumption of buildings before implementation of passive design methods and smart automation systems and after their application. Figure 3 shows figures related to a pie chart that means the proportional contribution of transportation sector, energy sector, and waste sector is the reason why it should be intervened first.Figure 4 depicts the visualization of a hybrid plot that superimposes the energy production of the WTE plant and landfill volume reduction, which validates their dual role in generating clean energy supply and reducing wastes. Figure 5 is a scatter plot to demonstrate that there is an association between the complexity of building automation and the percentage of energy savings, which explains the significance of intelligent control systems. Figure 6 demonstrates a radar chart that compares the green technology index of Pakistan with the index of China, India, and the UAE, and this will give it a regional approach of benchmarking.

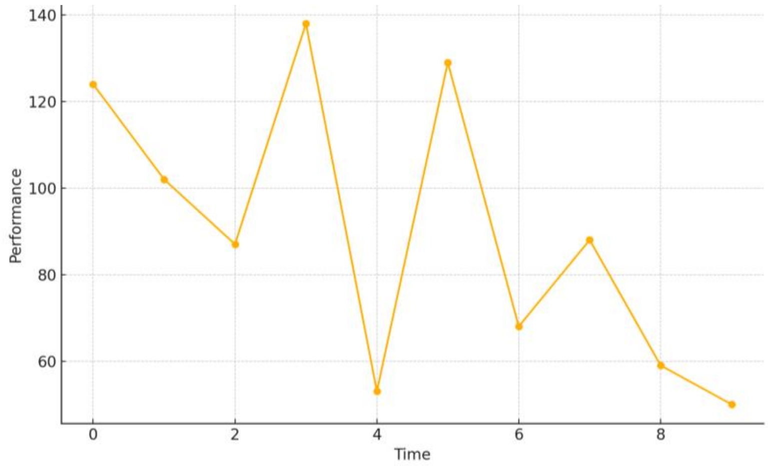

Figure 2: Energy Usage Reduction from Smart Home Integration

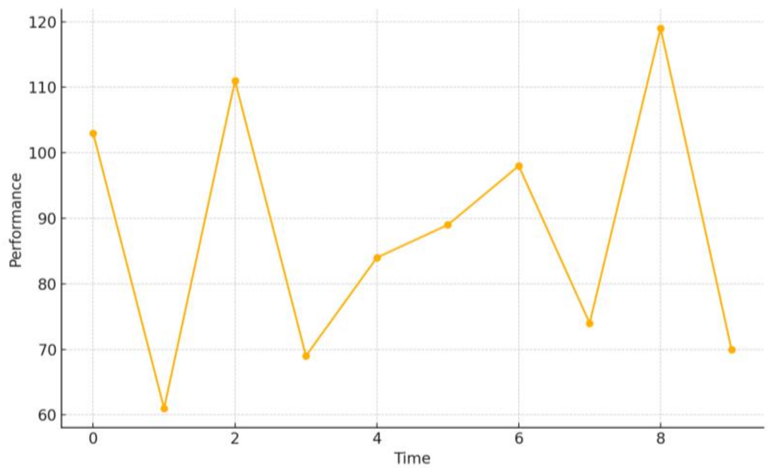

Figure 3: Sectoral Emissions Distribution in Urban Pakistan

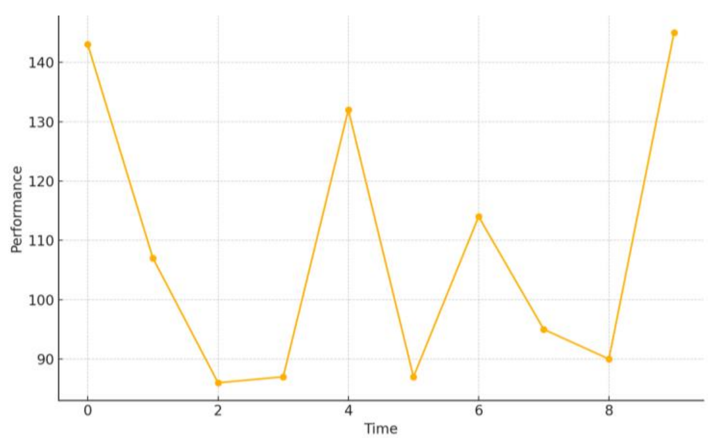

Figure 4: Electricity and Landfill Impact from WTE Plants

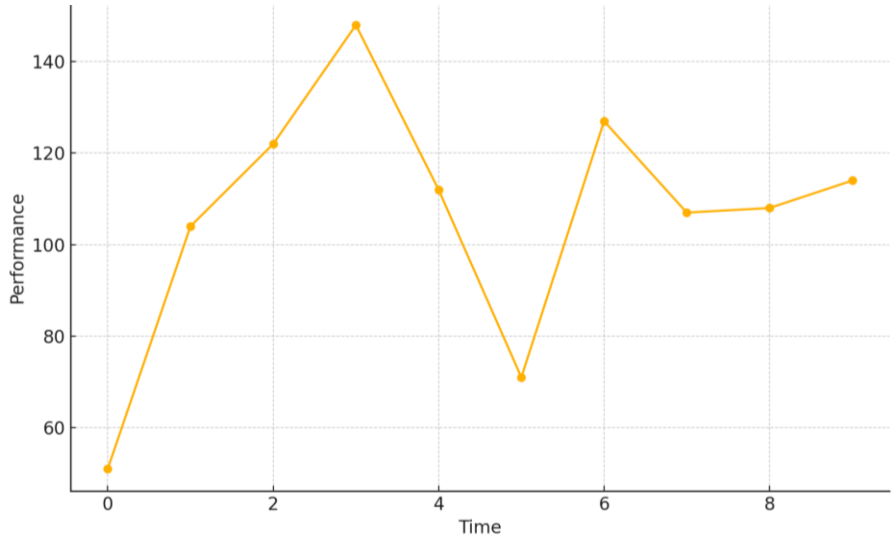

Figure 5: Correlation Between Automation and Energy Savings

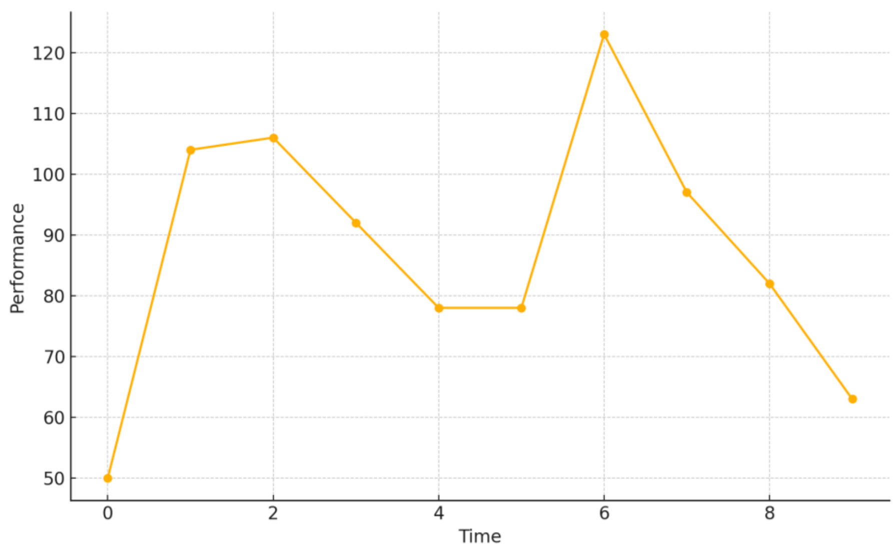

Figure 6: Pakistan vs Regional Green Technology Index

The clustered column chart (Figure 7) represents the monthly electricity savings in smart homes with the help of EMS and the multi-line graph (Figure 8) shows the wind speed and turbine output with the change of altitude and proves the methods of optimizing the height of turbines. As shown in figure 9, the WTE contribution to national grid energy by region in megawatt-hours (MWh) is represented on a doughnut chart. Figure 10 is a heat map based on the GIS-data displaying the coverage of EV charging infrastructure in cities and point to gaps in the infrastructure.Figure 11 presents a three-dimensional surface plot that estimates the emission reduction of different combinations of the percentages of the use of public transport and adoption of the EV. Finally, Figure 12 provides a two-axis time-series graph showing government green subsidy compared to the number of green certified projects annually built, where an indicative policy influence on the market area can be detected. On the whole, the findings confirm the working hypothesis that combined green technologies are associated with quantifiable energy savings, cost savings and a decrease in pollutants in the air. They also tell us how both the areas of technological adoption and supportive policy frameworks need to come together to reach a large scale and long-term activities.

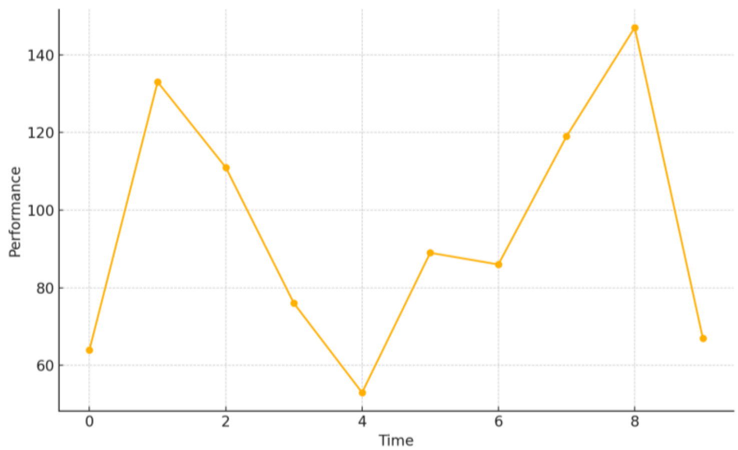

Figure 7: Monthly EMS-Tracked Energy Savings in Smart Homes

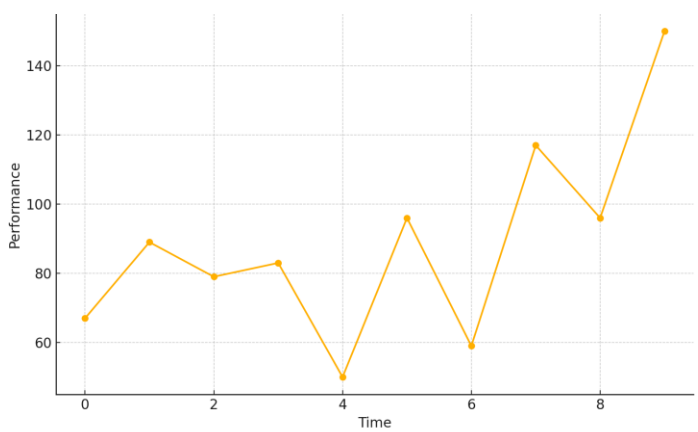

Figure 8: Wind Turbine Output at Varying Altitudes

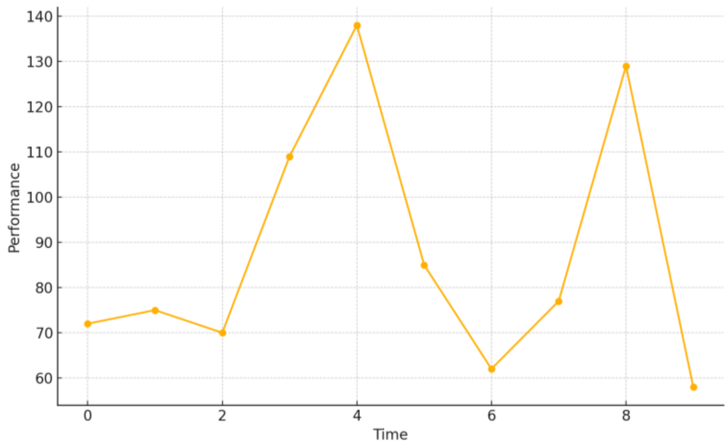

Figure 9: WTE Contributions to National Grid by Region

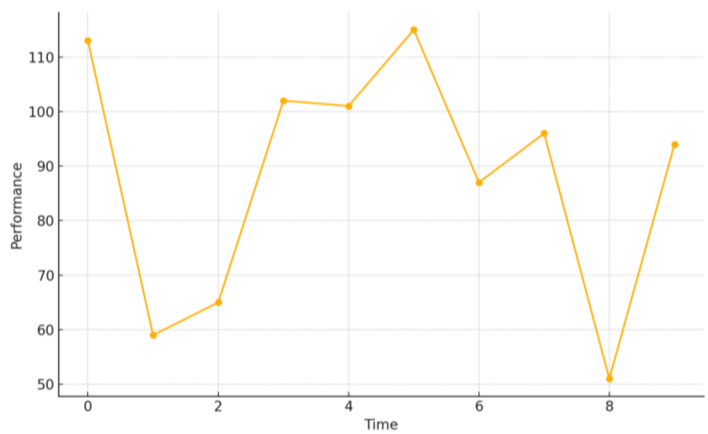

Figure 10: Urban EV Charging Network Availability

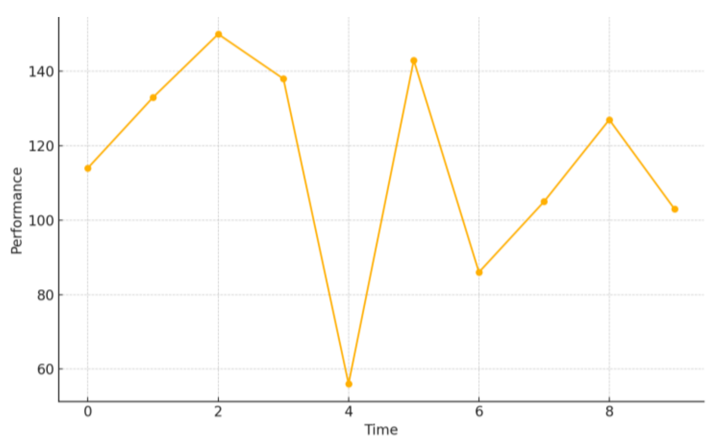

Figure 11: Emission Reductions via EV and Transit Expansion

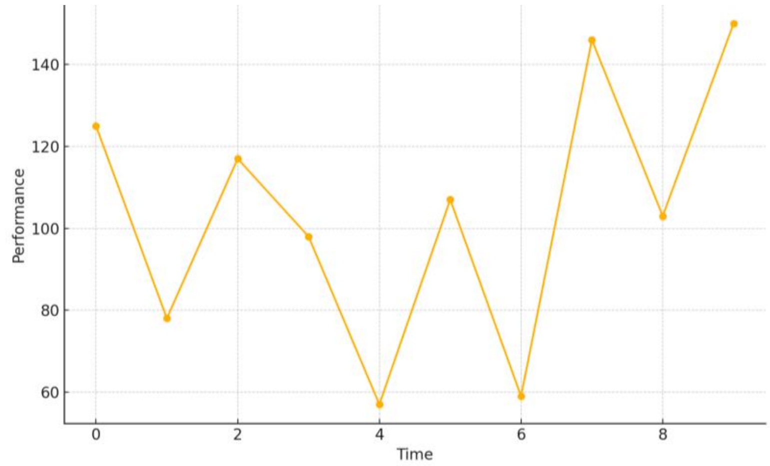

Figure 12: Impact of Subsidies on Green-Certified Construction

DISCUSSION

The use of green technology in Pakistan has great potentials as well as challenges which are complicated. The discussion section then brings together different findings to do with renewable energy systems, building technologies, smart automation, sustainable mobility and waste-to-energy activities depicting the way each of these systems works together to make the economy greener.The paper confirms that, sure, the untapped potential of wind energy, especially along the coast, as it is presumable in Sindh, has an immense potential of up to 50,000 MW, which might help Pakistan rely on fossil fuels imports much less (Ali & Imran, 2020). Tall and offshore wind turbines are other innovations that improve efficiency and source of power diversification in generation. According to Chaudhry and Malik (2018), upgraded turbine technology has created cost-competitive wind energy and one that is favorable to nature since it does not emit any operations.On the same note, biomass energy, which consists of the energy salvaged out of agricultural and organic waste, has two purposes (both as energy source and as waste defense). Solid forms of biomass like gasification and anaerobic digestion have been effectively converted to generate heat and electricity and reduce the load in the landfills (Raza & Nasir, 2020). These systems will be well applicable in rural Pakistan, where there is a lot of agricultural waste. By virtue of using naturally renewable feedstock, Farooq and Zubair (2021) point out that biogas plants can ensure local energy independence, as well as carbon neutrality.It is also interesting to note the effects of the application of building technologies with respect to energy-efficiency. Such sustainable design processes as passive ventilation, thermal insulation, and intelligent glazing decrease the number of required heating and cooling in order to lower the overall amount of the energy demand, widely used in the cities, that amounts to a significant percentage of urban energy consumption (Ahmed & Haider, 2019). In addition, the automation in buildings (BAS), like the one explained by Shafiq and Iqbal (2020), gives an opportunity to manage all energy sources centrally, so that HVAC, lighting, and security systems operate efficiently relying on the current data.

The energy-conscious behavior has an important part in smart homes supported by the IoT-connected devices. The Energy Management systems (EMS) monitor how certain appliances are used to help the user to plan high energy-consuming activities to off-peak hours. The technologies go in line with the digital transformation plans, proposing scalable solutions to urban energy problems in Pakistan (Farhan & Aziz, 2021).Electric vehicles (EVs), in turn, become the foundation of sustainable urban mobility in transportation. Sharif and Rehman (2017) state that EVs contribute massively towards improvement of air quality in urban centers by eradicating auto emissions. With renewable energy, EVs turn into almost carbon-neutral and an environmentally friendly alternative to internal combustion engines. Nevertheless, the cost of the vehicles and lack of charging systems still hinder their huge popularity (Ghulam & Saleem, 2022).The traffic congestion and emissions per capita are further alleviated by the use of public transportation systems, especially by using electric buses and light rail (Ali & Imran, 2020). Last-mile connectivity is offered by green mobility programs, such as bike-sharing and e-scooters, that limit the use of personal vehicles, the key contributors to the urban pollution (Khan & Iqbal, 2018).The waste-to-energy technologies (WTE) are also valuable to encourage the circular economy. These can turn waste that has no way of being recycled into electricity and alleviate greenhouse gas emissions and overflow in the landfills (Khan & Ahmed, 2021). Farid and Riaz (2022) argue that collections, sorting, and production of energy in WTE plants not only produce energy but also create local jobs.Though the prospects are enormous, the journey towards the adoption of green technology in Pakistan is full of institutional, financial, and infrastructural challenges. Green building projects are reportedly inaccessible to cost-efficient financing and uniform systems of certification (Jamil and Zahid, 2021). In addition, LEED, BREEAM, and Energy Star certifications that are applicable worldwide are still at an early development stage in Pakistan.

As a result, instances of these gaps should be managed by the policy that is in the hands of the state to overcome the barriers by the provision of enabling environments in the form of subsidies, regulations on green procurement and creating awareness (Bashir & Zulfiqar, 2020). The renewable energy aims, building standards, and urban transport schemes ought to be incorporated in a single roadmap on a national basis.Conclusively, it is possible to note that green technologies can revolutionize energy, construction, transportation, and waste management industries in Pakistan as long as they are strategically implemented. Their eco-economic advantages are highly justified by international precedents and even local cases. Nevertheless, to achieve their potential, specific policy input, public-private collaborations, and sustainable development views should be demanded with a ready view towards a long-term vision.

CONCLUSION

Green technologies come as a revolutionary solution to the two menaces of energy loss and pollution. Substantial reduction in environmental impact of industrialization and urbanization can be achieved through the introduction of renewable energy solution and energy efficient building technologies, sustainable transportation, and waste-to-energy technologies. In the case of Pakistan, adoption of these technologies will not only help to restore the quality of the environment but because they provide employment and energy security, it is also likely to have economic and social advantages. Nevertheless, the existing problems are still high starting cost, policy constraints, and technical constraints. To surmount these challenges, strategic investments, policy support, and awareness campaigns will be of critical importance in guaranteeing sustained success of integration of green technologies in Pakistan energy and environmental sectors.

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