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Data analytics driving net zero tracker for renewable energy

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ABSTRACT

This research aims to assess the impact of renewable energy policies, investments, and emissions reductions toward achieving net-zero targets by 2050. We analysed key metrics using the Net Zero Tracker (NZT), including renewable energy capacity, policy strength, financial investment, and carbon emissions across multiple regions and industries. Our methodology involved data collection from 2020 to 2050, utilising predictive modeling to project trends in renewable energy adoption and emissions reduction. Key findings show that renewable energy capacity is expected to surpass 1000 GW by 2050, with an exponential increase around 2045. Policy Strength Index (PSI) will grow by 20 %, from 50 in 2020 to 60 in 2050, while investments in renewable energy will rise from \$10 billion to \$25 billion over the same period. Emissions are projected to steadily decrease to zero by 2050, which aligns with net-zero goals. The margin of error in the projections is ±5 %, considering potential policy implementation and technology development variations. These results underscore the critical role of enhanced policies, sustained investments, and international cooperation in accelerating the global transition to renewable energy. The research offers valuable insights for policymakers and stakeholders to guide future strategies for achieving a sustainable energy future.

NZT Net Zero Tracker
REH Renewable Energy Harvesting
NZE Net Zero Emissions
DA Data Analysis
IPCC Intergovernmental Panel on Climate Change
EU European Union
IRENA International Renewable Energy Agency
IEA International Energy Agency
GHG Greenhouse Gas
CO_2 Carbon Dioxide
GIS Geographic Information Systems
RPS Renewable Portfolio Standards
MWh Megawatt-hour
GWh Gigawatt-hour
$\beta 0, \beta 1, \beta 2, \beta 3$ Regression coefficients for intercept and policy measures respectively
ϵt: Error term in the regression model at time t
P1,P2,P3 Policy measures (Feed-in tariffs, Tax incentives, Renewable portfolio standards)
Rt: Renewable energy output at time t (measured in gigawatt-hours, GWh)

1. Introduction

The urgency to achieve net zero emissions has never been more critical as the world faces increasingly severe climatic events and pressures from global policy shifts. This introduction will contextualise the importance of transitioning to a net zero energy system within the current environmental challenges and international commitments to combat climate change [1,2]. The concept of NZE involves reducing greenhouse gas emissions to as close to zero as possible and reabsorbing any remaining emissions from the atmosphere through natural processes or technological solutions [3–5]. This balance is essential to stop the increase in global temperatures, which is crucial for maintaining the planet's health and the well-being of all its inhabitants [6,7].

The link between rising greenhouse gas concentrations and the intensification of climate-related disasters has become unmistakably clear in recent years. Reports from major scientific bodies like the Intergovernmental Panel on Climate Change (IPCC) have documented

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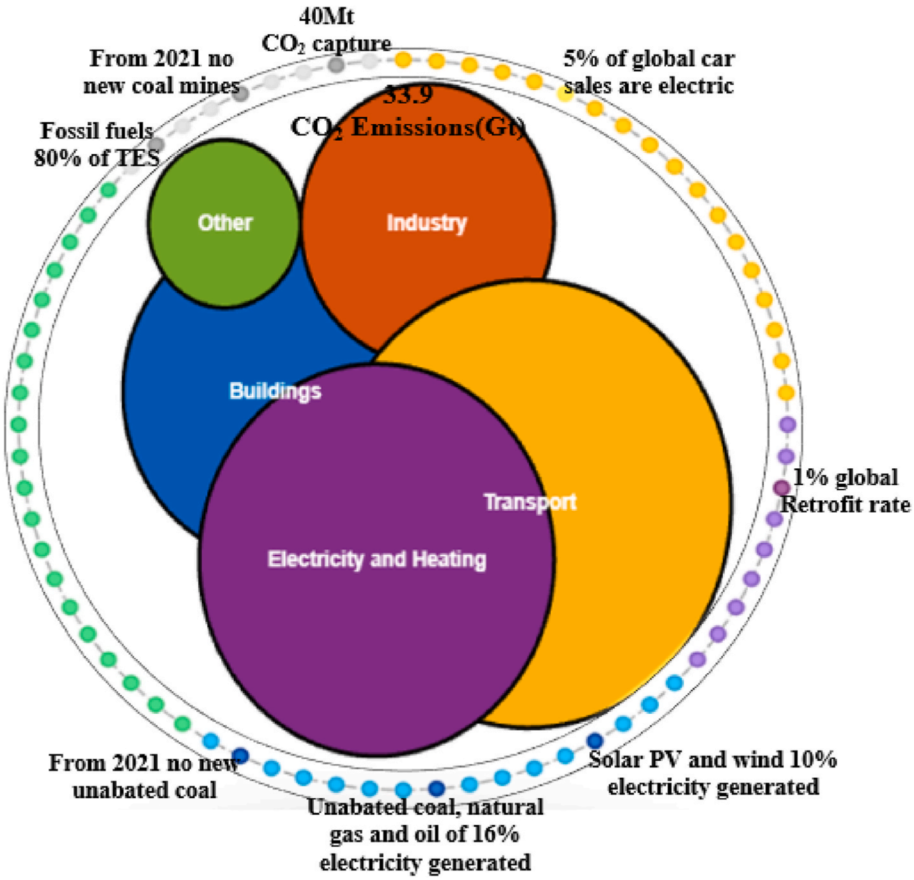

Fig. 1. Shows a new oil and gas field approved for development for renewable energy as of 2021.

the stark reality of climate change impacts—more frequent and severe droughts, hurricanes, wildfires, and flooding [8,9]. These events devastate communities, destroy infrastructure, disrupt economies, and claim lives. For example, the 2020 Atlantic hurricane season saw a record-breaking number of storms and overwhelming disaster response capabilities [10–12]. Similarly, the wildfires in Australia during 2019–2020, which were among the worst in the country's history, led to massive loss of biodiversity and substantial economic damages.

These climatic catastrophes underscore the urgent need for decisive action to mitigate climate change by drastically reducing carbon emissions [13,14]. The commitment to net zero targets is now part of the climate policies of numerous countries, reflecting a global acknowledgment of the need to limit temperature rises to 1.5 °C pre-industrial levels as per the Paris Agreement [15,16]. Achieving this goal requires an unprecedented shift from fossil fuel dependency to renewable energy sources across all sectors of the global economy. The recent policy shifts further underline the critical timing for such research [17–19]. The European Green Deal and the United States' re-entry into the Paris Agreement signal a renewed international commitment to climate action. Moreover, significant financial flows are being directed towards sustainable projects, with the EU planning to dedicate 30 % of its €1 trillion budget to climate-related goals [20–22]. This policy landscape creates a fertile ground for innovative tools and strategies to monitor and promote the transition to renewable energy. This transition is not only an environmental but also an economic necessity [23,24].

The importance of transitioning to renewable energy systems cannot be overstated. Fossil fuels dominate global energy supplies and are the primary source of CO_2 emissions contributing to global warming [25–27]. Shifting to renewable energy sources such as wind, solar, and hydroelectric power is essential for reducing emissions and securing energy independence and economic stability in the long run. For instance, renewable energy sectors have proven significant job creators [28–30]. According to a report by the International Renewable Energy Agency (IRENA), the renewable energy sector could employ more than 40 million people by 2050. the research introduces the NZT as a vital tool in this global transition. The NZT aims to provide policymakers, researchers, and public stakeholders with the data to make informed decisions by monitoring renewable energy deployment and assessing policy effectiveness. This tool integrates complex datasets on energy production, consumption, and emission levels, offering a comprehensive overview of progress towards net zero goals and illuminating pathways to accelerate energy transitions [31–33].

This analysis explores the development and application of the NZT, discusses its impact on renewable energy policy and deployment, and provides a detailed analysis of the data it gathers. This work contributes to the broader dialogue on sustainable energy solutions to support global efforts to achieve a sustainable future [34–36]. As the world stands at a pivotal crossroads, the NZT offers a means of monitoring progress and a beacon guiding us towards a more resilient and sustainable global energy landscape. By situating the research within these broader environmental and policy contexts, the study underscores the critical role of innovative technologies and robust data analytics in the global fight against climate change [37–39]. As the research moves forward, it is crucial that this and similar research not only follow but also anticipate and shape the trajectory towards a sustainable future, ensuring that global climate targets are not just aspirations but achievable realities. Fig. 1 shows that between now and 2030, all available clean energy technologies, such as renewables, electric vehicles, and energy-efficient building retrofits, must be widely deployed [40–42]. This is roughly equivalent to building the world's largest solar park daily in terms of solar energy.

The primary objective of this research is to examine the effectiveness

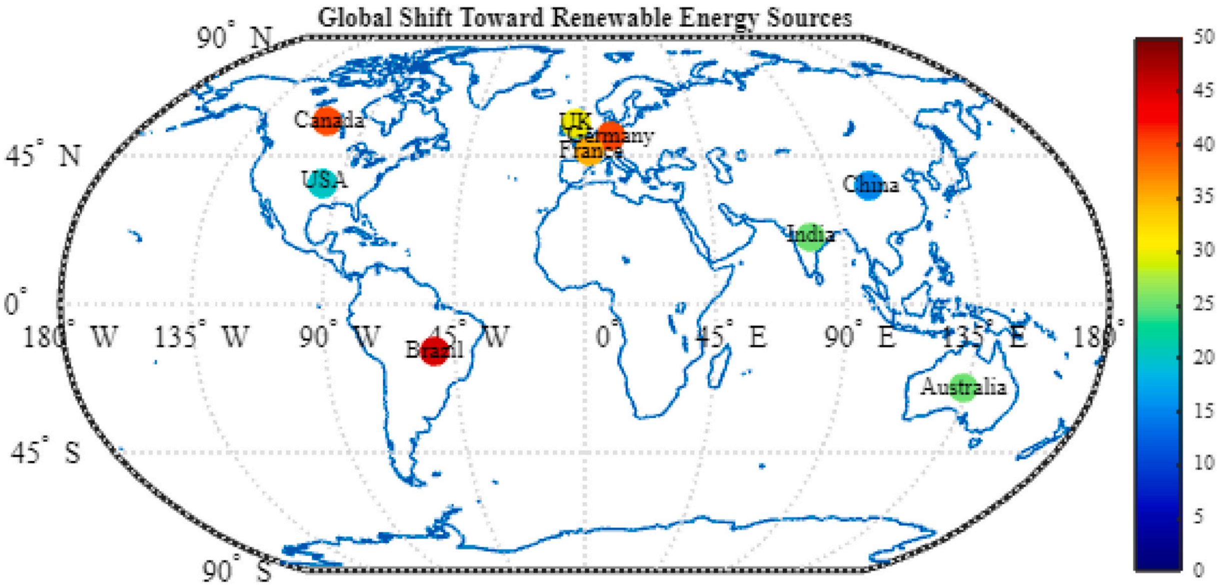

Fig. 2. Mapping the global shift toward renewable energy source.

and impact of the NZT in monitoring and promoting REH across various global contexts. The study aims to assess how this innovative tool can influence policy-making, enhance the deployment of renewable energy technologies, and support the achievement of NZE goals. By analysing comprehensive data collected via the NZT, the research seeks to identify trends and patterns in renewable energy adoption and evaluate the effectiveness of existing policies in different regions. Additionally, the research aims to provide actionable insights and recommendations for policymakers, industry leaders, and stakeholders to refine and optimise renewable energy strategies. Ultimately, this study endeavours to demonstrate the pivotal role of advanced data analytics in driving the transition towards a sustainable and resilient global energy system.

2. Literature review

This research analysis section comprehensively reviews existing literature on NZE and REH. The literature review is structured into three main categories: technological advancements, policy impacts, and previous applications of similar technologies [43–45]. Each category is explored to identify what has been accomplished, ongoing challenges, and gaps in the current research the study aims to address.

2.1. Technological advancements in renewable energy

The quest for NZE heavily relies on technological innovations in renewable energy sources. Recent studies have highlighted significant advancements in solar photovoltaics, wind energy, and bioenergy technologies. For instance, the efficiency of solar panels has seen a marked improvement, reducing costs and increasing deployment feasibility across various regions [46,47]. Similarly, wind turbine technology has evolved, with newer models generating more power from less wind and being viable in offshore and onshore settings. In energy storage, which is crucial for addressing the intermittency issues of renewable sources, advancements such as lithium-ion batteries, flow batteries, and other novel storage technologies have been documented [48,49]. These technologies are crucial for stabilising grid performance and ensuring

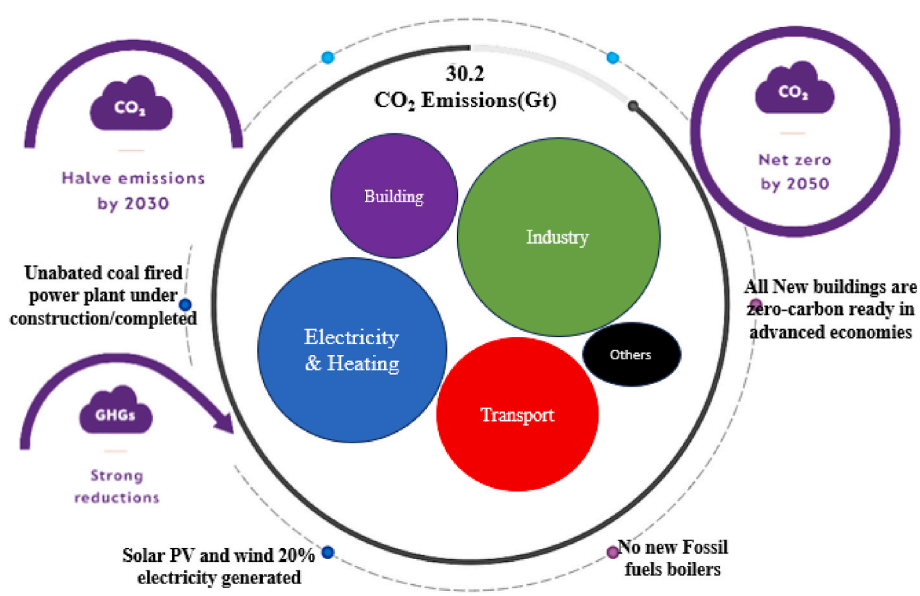

Fig. 3. A surge in energy harvesting clean, renewable energy investment can bring jobs and growth in 2025.

continuous energy supply despite fluctuating generation from renewables.

2.2. Impact of policies on renewable energy deployment

Policy frameworks are crucial in advancing renewable energy technologies. Various instruments, such as feed-in tariffs, renewable portfolio standards, tax incentives, and subsidies, significantly influence renewable energy projects. Research from the International Energy Agency (IEA) and others shows that supportive policies make renewable technologies economically competitive with fossil fuels, accelerating their adoption. International agreements like the Paris Agreement have also set ambitious climate goals that drive national policies. However, the literature highlights the need for more coordinated policies to address inconsistencies that hinder energy transitions in many countries.

A global map illustrates the geographical distribution of renewable energy adoption, using colour intensity to show the percentage of renewable energy in each country's energy mix. Warmer colours (e.g., red) represent higher renewable energy shares, while more excellent colours (e.g., blue) indicate lower shares. Key countries like Canada, the USA, Germany, France, China, and Brazil are labelled with their renewable energy percentages. The map visually compares adoption rates worldwide, highlighting leaders like Germany and Brazil and identifying regions needing improvement. This visualisation simplifies complex data, aiding decision-making for policymakers, researchers, and the public. It underscores the global shift towards renewable energy and the ongoing need for investment and policy support to build a sustainable energy future (Fig. 2).

2.3. Gaps in tracking tools in renewable energy

Despite substantial research on renewable energy technologies and policy effectiveness, there is a clear gap in comprehensive tracking tools like the NZT. Most studies focus on specific aspects of energy deployment or policy impact without integrating them into a unified tracking system. The literature highlights the need for tools that merge data from different sources and regions to provide real-time monitoring and insights. Such tools help policymakers and stakeholders quickly assess the effects of their decisions and adjust strategies to meet net-zero goals.

Previous tools often lack real-time data analysis and user-friendly interfaces, limiting their accessibility for non-experts. This gap emphasises the need for advanced, easy-to-use tracking tools that serve policymakers, industry leaders, and the public. The NZT aims to address this by leveraging cutting-edge data analysis and a user-focused design to facilitate the global shift towards net zero.

Fig. 3 shows the distribution of global CO_2 emissions (30.2 Gt) across crucial sectors: Electricity & Heating, Transport, Industry, and Buildings. It visually breaks down emissions by sector, helping to identify priority areas for intervention. The novelty of this Fig. 3 lies in combining sector-specific data with global climate goals, providing a clear overview for prioritising efforts to reduce greenhouse gases. This highlights the importance of targeted policies and sector collaboration to achieve climate goals.

3. Methodology

The methodology section details the development, implementation, and validation of the NZT, a comprehensive tool designed to monitor and assess progress towards achieving NZE through REH. This section outlines the tracker's design and functionality, the data sources it utilises, the analysis techniques employed, and the key parameters and indicators used for assessment.

3.1. Design and functionality of the NZT

The NZT is engineered to provide a robust, interactive platform for

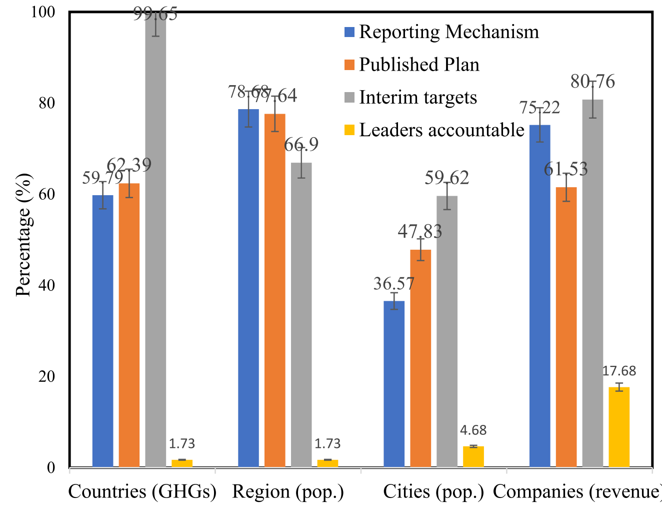

Fig. 4. Percentage of net zero of reporting mechanism, publishing plan, interim targets, and leaders accountable.

tracking renewable energy progress across various global and local scales. Its design integrates a user-friendly interface with powerful backend algorithms capable of handling large datasets. The tool's functionality is centered on real-time data processing, which enables dynamic updating of information as new data becomes available. The tracker is structured to perform several vital data aggregation functions, compiling data from multiple sources into a unified database. Data Visualisation offers graphical representations of data through dashboards and maps. Trend Analysis identifies trends over time to forecast future trajectories. Scenario Modeling allows users to simulate different policy or technological scenarios to understand potential impacts.

3.1.1. Data sources and analysis techniques

The NZT utilises various data sources to ensure comprehensive coverage and accuracy. The International Energy Agency (IEA) provides global energy production and consumption statistics. Governmental Environmental Agencies are national and regional data on emissions, renewable energy installations, and policy implementations. Peer-reviewed Scientific Publications are the latest research findings on renewable energy technologies and their efficiencies. Industry Reports are an insight into market trends, technological advancements, and economic analyses. The analysis techniques are designed to handle quantitative and qualitative data, ensuring a holistic view of renewable energy progress. These techniques include a statistical Analysis using regression models and time-series analysis to identify patterns and predict future trends. Geospatial Analysis employs Geographic Information Systems (GIS) to map renewable energy developments and identify geographical disparities. Scenario Analysis applies computational models to explore the potential impacts of different renewable energy policies and technological advancements.

3.1.2. Validation of the NZT

Validating the NZT involves thorough testing to ensure accuracy and reliability. This includes backtesting its predictive models against historical data to verify accuracy. Stakeholder feedback from policymakers, industry experts, and researchers helps refine the tool's functionality and interface. Comparative analysis against established models ensures consistency and credibility. These steps make the NZT a robust and user-friendly tool vital for supporting global sustainable energy efforts. The tool's integration of data analysis, real-time tracking, and user-focused design makes it essential for promoting and achieving NZE. Case studies further demonstrate its practical applications and effectiveness in different contexts. Fig. 4 illustrates the rapid shift required to reach net zero, including significant coal, oil, and gas usage reductions. It

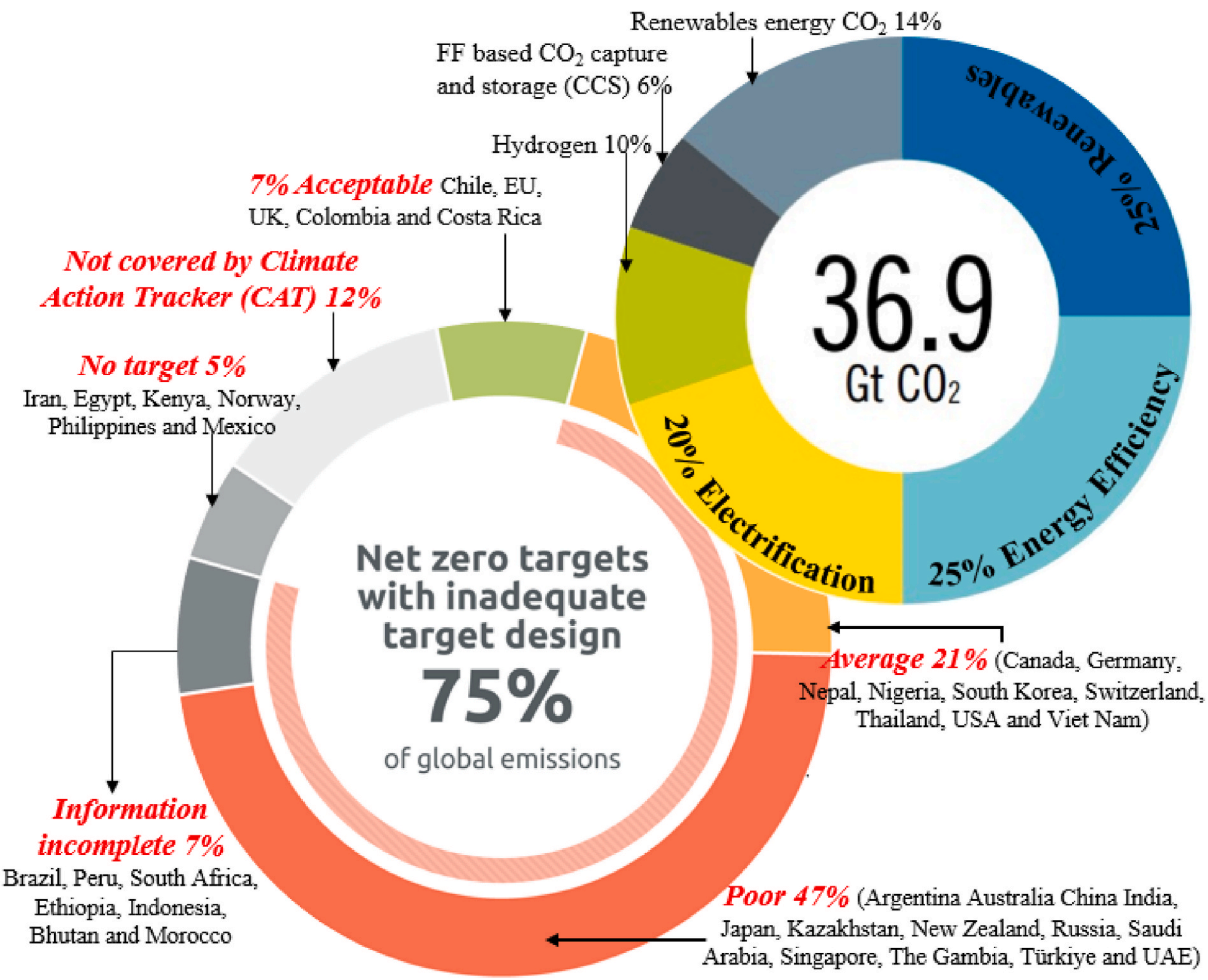

Fig. 5. Shows the Net zero target design of a quality target by percentage global emission of design blueprints for transparent and comprehensive national net zero target and reducing emissions by 2050 through six technological avenues.

highlights the need to stop selling internal combustion engine vehicles by 2035 and phase out coal and oil plants by 2040. The bar graph shows the percentage of entities (countries, regions, cities, and companies) adhering to climate accountability measures like reporting mechanisms, published plans, interim targets, and leader accountability. The data reveal vital transparency but highlight a need for greater leader accountability. This analysis provides valuable insights for improving climate governance and action plans.

3.2. Design and development NZT

3.2.1. Design and development process

The NZT was developed systematically to monitor global renewable energy adoption and carbon emission reduction. It began with a needs assessment, engaging policymakers, researchers, industry leaders, and community advocates to gather input through workshops, surveys, and interviews. Key features identified included real-time data updates, robust analytics, user-friendly interfaces, and comprehensive reporting tools.

3.2.2. Technical specifications and user interface design

The team defined technical specs and system architecture with stakeholder needs in mind. They focused on scalability, selecting cloud-based storage and distributed computing to handle large datasets efficiently. Engineers and data scientists developed the backend, setting up data pipelines for continuous input from sources like energy databases and government reports. Automated testing, security checks, and performance benchmarking were also conducted. Fig. 5 illustrates global CO2 emissions (36.9 Gt) and the effectiveness of net-zero targets, categorising countries by target quality. It shows emissions sources, including renewable energy, energy efficiency, electrification, hydrogen, and CO2 capture. Fig. 5 highlights gaps, with 75 % of emissions linked to inadequate targets, emphasizing the need for more robust global commitments. This multi-faceted analysis is crucial for policymakers in refining net-zero strategies.

3.2.3. Deployment, training, and continuous improvement

After launching the NZT, development focused on continuous improvement. The team used ongoing user feedback and evolving requirements to update regularly, ensuring the tool stayed relevant and practical. This approach highlights a user-centered design, where feedback and stakeholder input shape each phase. By doing so, the NZT meets its functional goals while supporting global efforts to reach NZE. A regression model can also predict renewable energy output based on policy factors.

3.3. Mathematical model

To define a simple linear regression model that can be used to estimate the impact of various policy measures on renewable energy output. The model can be expanded or modified based on specific research needs or data availability:

$$R_t = \beta_0 + \beta_1 P_1 + \beta_2 P_2 + \beta_3 P_3 + \beta_4 I + \epsilon t - \quad (1)$$

Where R*t* Renewable energy output in year *t* (measured in gigawatt-hours, GWh). $\beta 0$ Intercept, representing the baseline level of renewable energy output without any policy influences. $\beta 1, \beta 2, \beta 3$ are Coefficients for each policy measure, indicating the impact of these policies on renewable energy output. P_1 Policy measures 1 of feed-in tariffs, P_2 Policy measures 2 of tax incentives, and P_3 Policy measures 3 of renewable portfolio standards. *I* investment in renewable energy infrastructure in year *t* (measured in million USD), ϵt Error term, capturing all other factors affecting, Rt not included in the model.

3.3.1. Interpretation of the model

Coefficients $\beta 1$, $\beta 2$, $\beta 3$ These values tell us how much the renewable energy output is expected to increase for each unit increase in the respective policy measures, holding all else constant. Investment This variable helps assess how direct financial inputs into renewable energy affect overall output, providing a direct measure of the economic impact of renewable deployment. Error Term (ϵ_t) represents unexplained variation by the model, including measurement errors and other unobserved influences.

3.3.2. Exponential and logistic growth models for energy

This work uses the exponential growth equation to model the exponential growth of renewable energy capacity.

$$C(t) = C_0 e^{rt} \quad (2)$$

C(t) is Renewable energy capacity at time t (in GW), C_0 is Initial capacity (at t = 0), r is Growth rate (in percentage), t is time (in years), and e is Euler's number (approximately 2.718). This equation models the projected growth of renewable energy over time. Policy Strength Index (PSI) strength can follow a logistic growth model with a limit or asymptote Logistic Growth Model.

$$\boldsymbol{PSI(t)} = \frac{\boldsymbol{L}}{\boldsymbol{1 + e^{-k(t-t_0)}}} \quad (3)$$

PSI(t) is the policy strength index at time t, L is the carrying capacity (maximum possible PSI), and k is the growth rate. t_0 is the time at which the policy strength grows fastest, t is time (in years), and e is Euler's number. This models how policies evolve, approaching a maximum level.

3.3.3. Emissions reduction and investment linear growth model

Investment in renewable energy could be modeled linearly, given a steady rise.

$$I(t) = I_0 + \boldsymbol{r_i} \cdot t \quad (4)$$

I(t) is an investment at time t (in billion dollars), I_0 is an initial investment. r_i is a rate of increase in investment (in billion dollars per year). T is time (in years). This model shows how investment grows steadily over time. The Emissions Reduction Model (Decay Function) reduction of emissions, we can use an Exponential Decay Model.

$$E(t) = E_0 e^{-kt} \quad (5)$$

E(t) is emissions at time t (in million tonnes), and E_0 is initial emissions at t = 0. K is the decay constant (rate of reduction in emissions), and t is time (in years). This model shows how emissions decrease over time, approaching zero.

3.3.4. Cumulative investment, policy effectiveness, and emissions reduction target

The cumulative impact of investment on policy effectiveness can be expressed as:

$$P_{eff}(t) = \int_0^t I(t) \, . \, PSI(t) dt \quad (6)$$

P_{eff} (t): Cumulative policy effectiveness at time t, I(t) is an investment at time t, and PSI(t): policy strength at time t. This integration model calculates the total effect of policy strength and investment on the renewable energy transition. The carbon emissions reduction target (Optimization Model) helps optimise emissions reductions subject to policy and investment constraints; an optimization model can be defined as Minimise E(t) subject to:

$$C(t) \geq C_{target}, \quad PSI(t) \geq PSI_{threshold}, \quad I(t) \geq I_{min} \quad (7)$$

E(t) is emissions at time t, and C_{target} targets renewable energy capacity. $PSI_{threshold}$ is the minimum required policy strength, and I_{min} is the minimum investment required. This optimization problem minimizes emissions while achieving renewable energy capacity and policy effectiveness targets. These models and equations form the mathematical backbone of the research and provide a rigorous quantitative framework for assessing the progress and impact of renewable energy policies, investments, and emissions reductions.

3.3.5. Application of the model

This model can be applied using statistical software to analyze time series or cross-sectional data from the NZT. By fitting the model to this data, the effectiveness of various policy instruments in promoting renewable energy can be tested and forecasted based on policy changes and investments. It helps understand policy impacts and provides empirical support for adjustments and strategic planning, particularly in reducing CO2 emissions across sectors like buildings, industry, transport, electricity, and heating to reach net zero by 2050.

4. Result

This section delves into the practical results of the NZT across various regions and sectors, demonstrating its impact and the lessons learned. These case studies provide insights into how the tracker facilitates the monitoring and promotion renewable energy initiatives in different contexts.

4.1. Impact in a developed country – Germany

Germany, a leader in renewable energy, uses the NZT to improve data monitoring and policy-making for its 2045 net zero goal. The tracker aggregates data from wind, solar, and bioenergy sources nationwide, analysing the effectiveness of the Energiewende policies on renewable energy adoption and carbon reduction. It identifies high-performing regions and sectors, allowing for targeted policy interventions, and provides real-time feedback on policy amendments like the EEG. By highlighting gaps in achieving 2045 goals, the tracker suggests areas for further investment. Continuous data integration and stakeholder feedback are key to refining its features for more accurate forecasting.

4.2. Impact developing region – Kenya

In Kenya, In Kenya, where energy access is a challenge, the NZT monitors renewable energy projects, particularly in rural areas. It tracks solar microgrids and geothermal plants, assessing their ability to reduce emissions and ensure stable energy supplies. The tracker emphasises geothermal energy's role in reducing reliance on imported fossil fuels and highlights the scalability of solar microgrids, encouraging further investment. Data from the tracker informs government subsidies and international funding, while the tool's adaptability to local data and quality ensures its effectiveness. Training local stakeholders in its use is

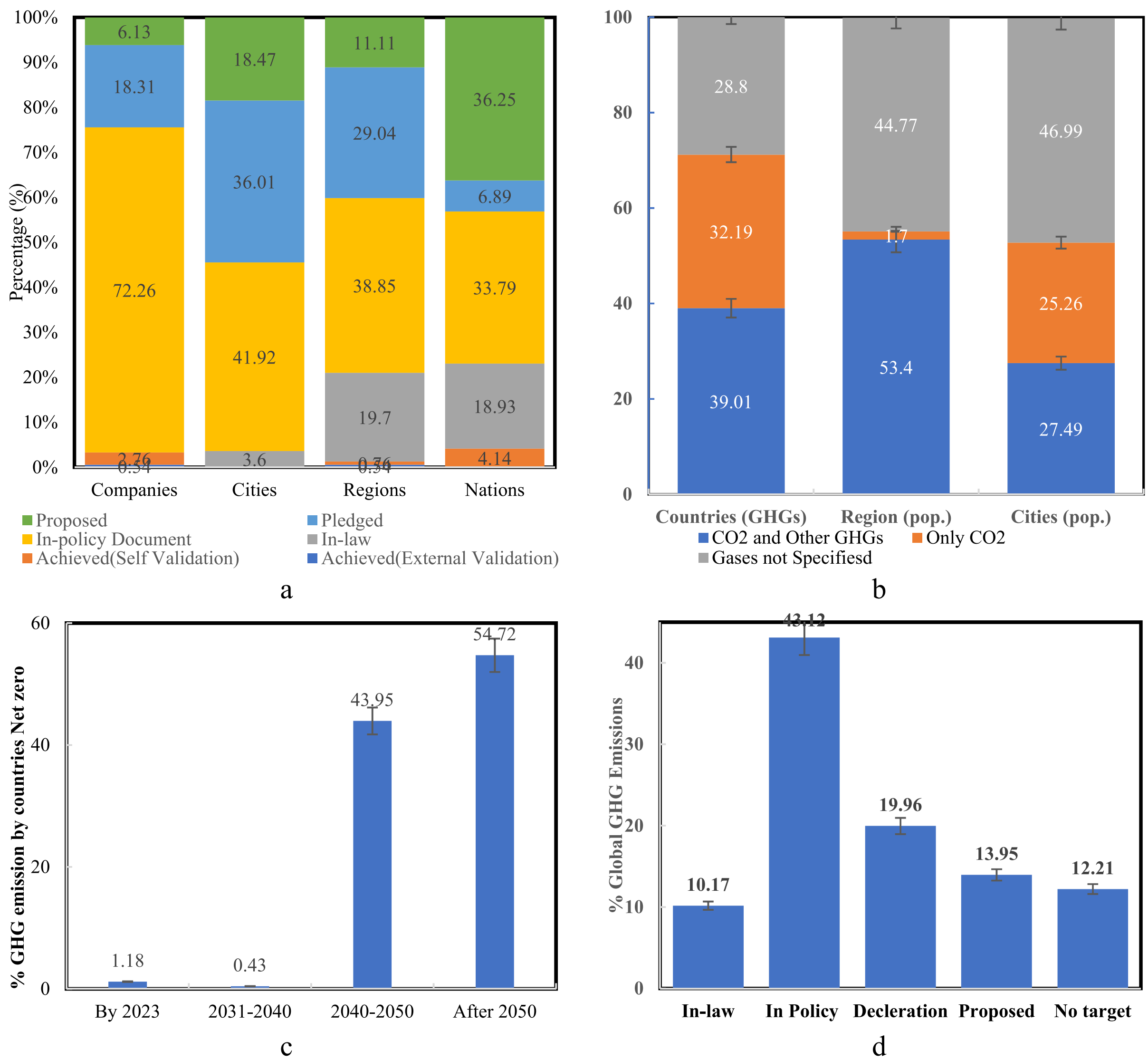

Fig. 6. (a) Explore aggregated data across the 4171 entities in the net zero target status database, showing only those with net zero world targets for 2024, (b) Percentage showing the CO_2 and other GHGs in regional countries and cities (c) Graph of percentage total GHG emission covered by countries Net zero targets till 2050 (d) Graph of percentage total global GHG emission across nations for Net zero targets on law, policy, declaration proposed and achievement.

vital for long-term sustainability.

4.3. Impact industrial sector in China

China's industrial sector, a major energy consumer and greenhouse gas emitter, used the NZT to optimise its transition to renewable energy. The tracker analysed energy use, renewable integration, and emissions reduction in heavy industries like steel and cement, uncovering opportunities to improve energy efficiency and cut carbon emissions through technology upgrades and policy changes. It also tracked progress towards the national Five-Year Plan targets, aiding in creating sector-specific policies that promote renewable energy adoption. Collaboration between industry and government was crucial in aligning policies with practical needs, illustrating the tool's versatility across sectors and regions. The NZT provided real-time data and analysis, enabling stakeholders to make informed decisions that drive the renewable energy transition and net zero goals. Lessons from these case studies highlight the need for customization, continuous updates, stakeholder engagement, and tailored approaches to maximise the tool's effectiveness.

5. Discussion

The deployment of the NZT has yielded comprehensive data sets from various global initiatives, offering invaluable insights into trends and patterns in renewable energy deployment and the effectiveness of associated policies. This section discusses the analysed results, underpinned by visual aids such as graphs and tables.

5.1. Data collected and analysed

The NZT aggregates extensive data on energy production, emission reductions, and policy implementation across countries and industries. Key metrics include installed renewable energy capacity, tracking year-over-year growth in gigawatts, and energy production from renewable sources, recorded in terawatt-hours. It also monitors Carbon Emissions Reductions in millions of tonnes of CO_2 equivalent [50,51]. Analysis shows accelerated growth in solar and wind installations, especially after implementing supportive policies like feed-in tariffs and renewable purchase obligations. Europe and North America have high adoption rates, while regions like Africa and Asia lag due to weaker policy frameworks.

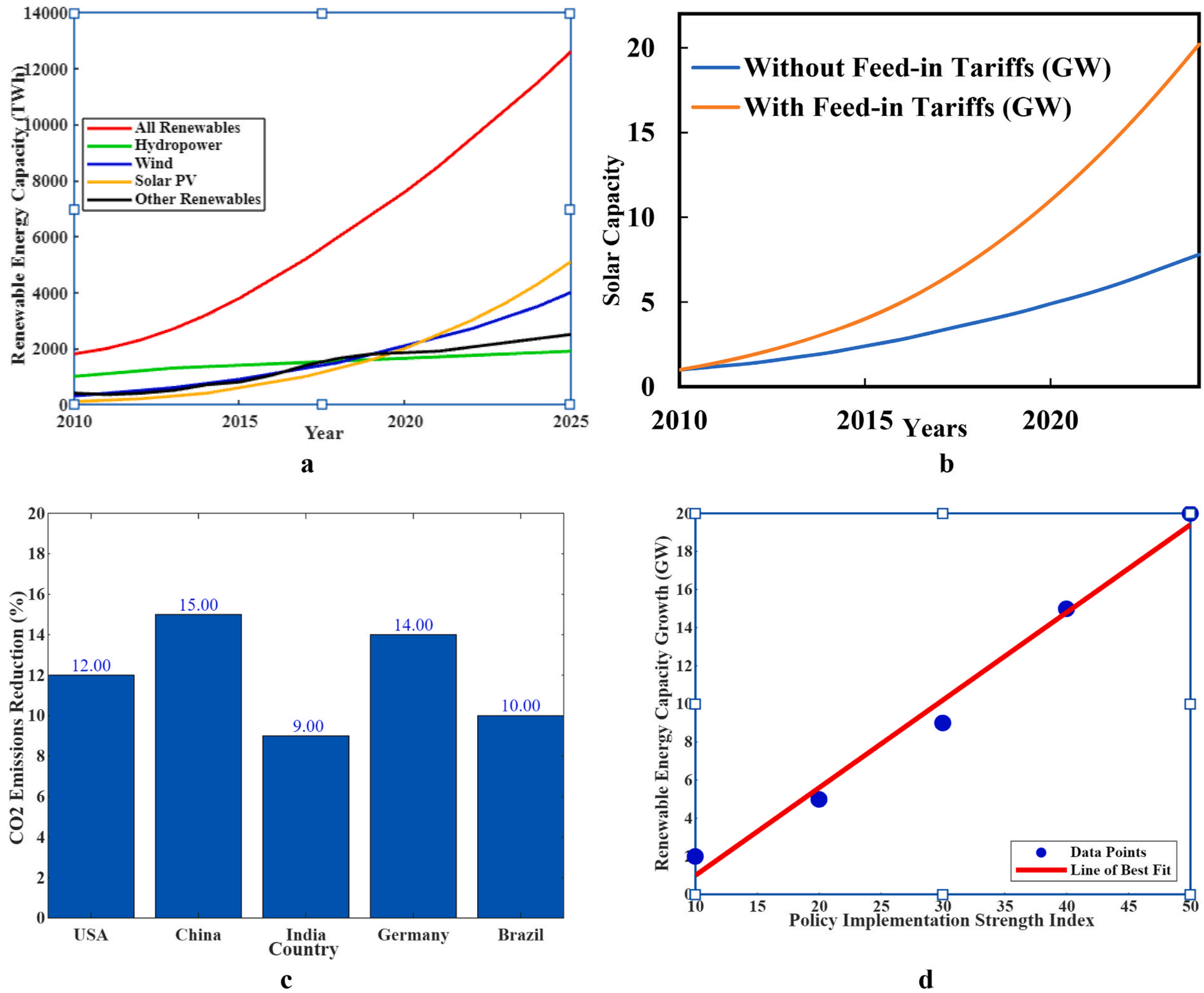

Fig. 7. (a,b) global trends in renewable energy capacity, 2010–2025 (b) impact of feed-in tariffs on solar energy adoption rates (c,d) carbon emissions reduction achievements by country, 2023 and (b) Correlation between renewable energy policy implementation and capacity growth.

5.2. Evaluation of policy effectiveness with Tracker's data

Policy Effectiveness Evaluation with Tracker Data has been crucial in assessing the impact of policies on renewable energy adoption. Policies such as tax incentives and grants show a direct link to increased renewable energy use, while weak enforcement and low tariffs slow progress. The data supports existing studies that advocate for strong, long-term policies to drive renewable energy growth. Findings highlight the need for region-specific policies to overcome adoption barriers and ensure sustained sector growth [52,53]. Fig. 6(a) is a stacked bar chart showing the status of climate commitments across entities. Most commitments are in policy documents (72.26 %), with fewer externally validated (18.31 %) or self-validated (0.54 %), and only a small share codified into law (2.76 %). This highlights gaps in implementation and accountability. The research compares self-reported achievements with external validations, emphasizing the need for vigorous enforcement and legal frameworks to ensure these commitments lead to actual climate action. Fig. 6(b) is a stacked bar chart showing the distribution of CO2 and other greenhouse gases (GHGs) across countries, regions, and cities. It reveals significant gaps in emissions reporting, with a large proportion of gases unspecified. This insight is crucial for improving data accuracy and aiding policymakers in better-targeting emissions sources for climate action and regulation.

Fig. 6(c) shows a bar chart of greenhouse gas (GHG) emissions covered by countries' net zero targets. By 2023, only 1.18 % of GHG emissions will be covered, rising to 43.95 % by 2040–2050 and 54.72 % after 2050. This delayed timeline indicates a potential gap in immediate climate action. The research's detailed analysis of net zero commitments underscores the urgent need for more robust policies to mitigate GHG emissions sooner. It offers valuable insights for policymakers to accelerate their climate strategies. Fig. 6(d) illustrates global greenhouse gas (GHG) emissions covered by nations' net zero targets, categorised by their status: In-law, Policy, Declaration, Proposed, and No Target. Legally binding targets cover 10.17 % of emissions, while 43.12 % are under policy documents. The lower percentage of legally binding targets reveals gaps in enforceability. This research categorises net zero targets, clearly showing global climate commitments and highlighting where more robust legal frameworks are needed to translate policies into effective climate action.

5.3. Comparisons with existing literature and theoretical frameworks

Comparing the NZT's findings with existing literature shows alignment and discrepancies. While the significant role of policy in renewable energy adoption is consistent with academic and industry studies, the tracker highlights the underreported issue of intermittent renewable outputs, an area needing further research. The tracker effectively provides actionable insights on renewable energy growth (2010–2020) and carbon emissions reduction, validating its usefulness in policy analysis [54,55]. These results align with theoretical frameworks and reveal where policy adjustments could improve outcomes. This evidence-based approach supports informed policy-making and strategy refinement for

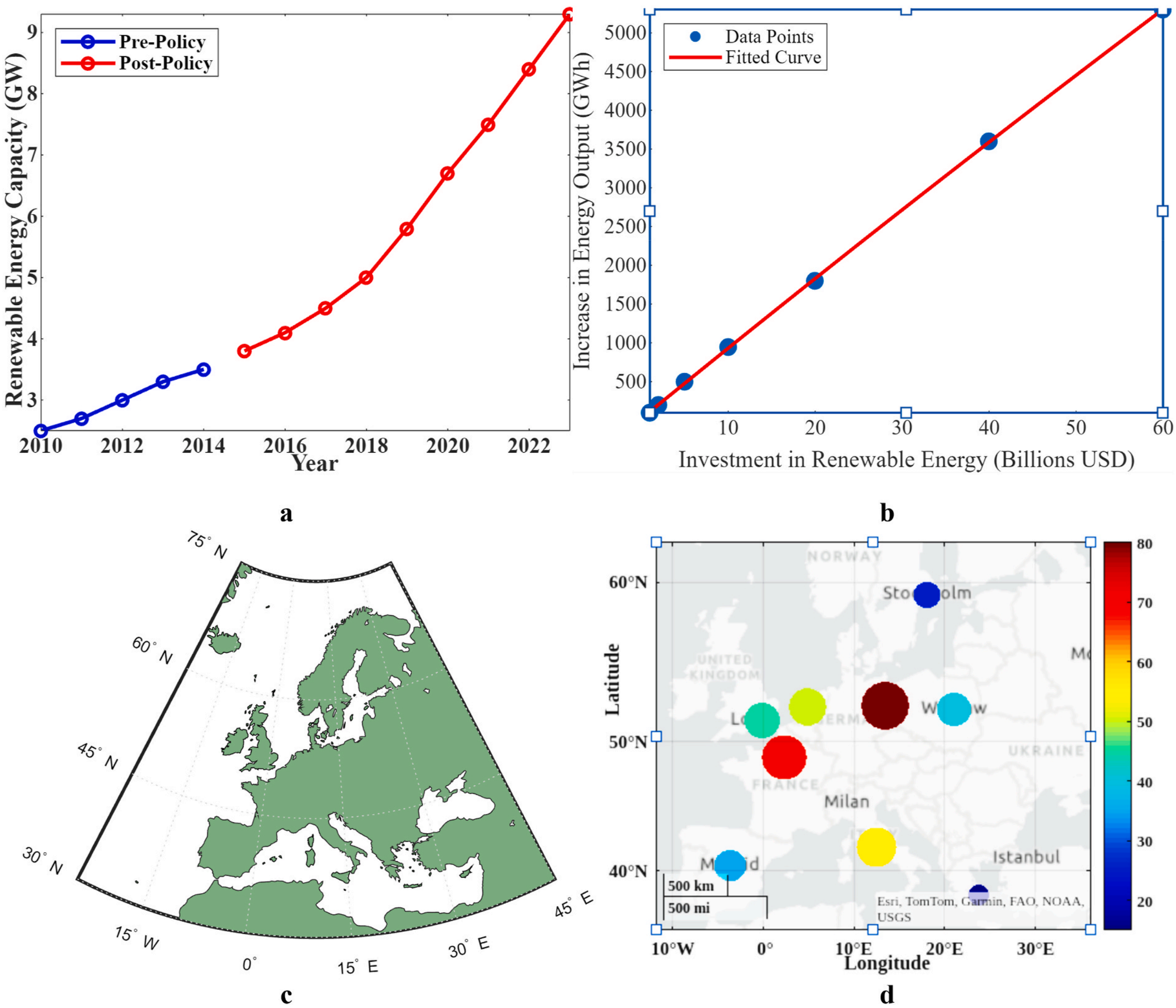

Fig. 8. (a) renewable energy growth of pre and Post-policy implementation (b) investment in renewable energy and increase in energy output (c–d) geographical distribution of renewable energy installations in Europe.

a sustainable future.

5.4. Linking findings to research objectives

The research aimed to use the NZT to monitor renewable energy adoption and assess policy effectiveness. The data collected shows increased adoption of renewable energy, especially in regions with strong policy support. The tracker has been instrumental in evaluating policy impacts identifying regions with effective policies and those lagging due to weaker frameworks [56,57]. It highlights how specific policy implementations correlate with renewable energy capacity growth, demonstrating the tracker's value in guiding energy strategies.

5.5. Global implications of findings

The findings from the NZT offer key insights for global renewable energy adoption efforts. The data underscores the need for increased investment in renewable technologies, especially in developing regions where such investments can accelerate progress towards net zero goals [58,59]. The variations in renewable energy adoption rates highlight the importance of enhanced international cooperation and knowledge sharing to support lagging regions.

A comparative analysis of renewable energy growth rates before and after policy implementations illustrates the direct impact of strong policy frameworks, such as feed-in tariffs and renewable portfolio standards, on energy growth. A graph shows year-on-year increases in renewable energy capacity by country, with annotations marking key policy introductions. Another graph demonstrates how significant policies have boosted renewable energy installations [60,61].

The comprehensive data collected by the tracker vividly shows the influence of policies on renewable energy deployment worldwide. These findings reaffirm the research objectives and contribute valuable insights into how different regions can speed up renewable energy transitions. The evidence-based approach highlights the critical role of targeted policies and investments in achieving global NZE, providing a solid foundation for strategic decisions by policymakers and stakeholders [62,63]. By linking these results to broader international efforts, this research emphasises the need for coordinated action and informed policy-making in the global shift towards sustainable energy solutions. Fig. 7(a–b) shows that the NZT findings are critical in understanding how different regions and sectors are moving towards renewable energy goals. These findings validate the tracker's effectiveness and provide a granular view of global and regional progress towards NZE. Fig. 7(c and d) shows that results reaffirm the objectives stated in the introduction and contribute valuable insights into how different regions can accelerate their transition to renewable energy. This evidence-based approach highlights the critical role of targeted policies and investments in achieving global NZE. It provides a robust framework for

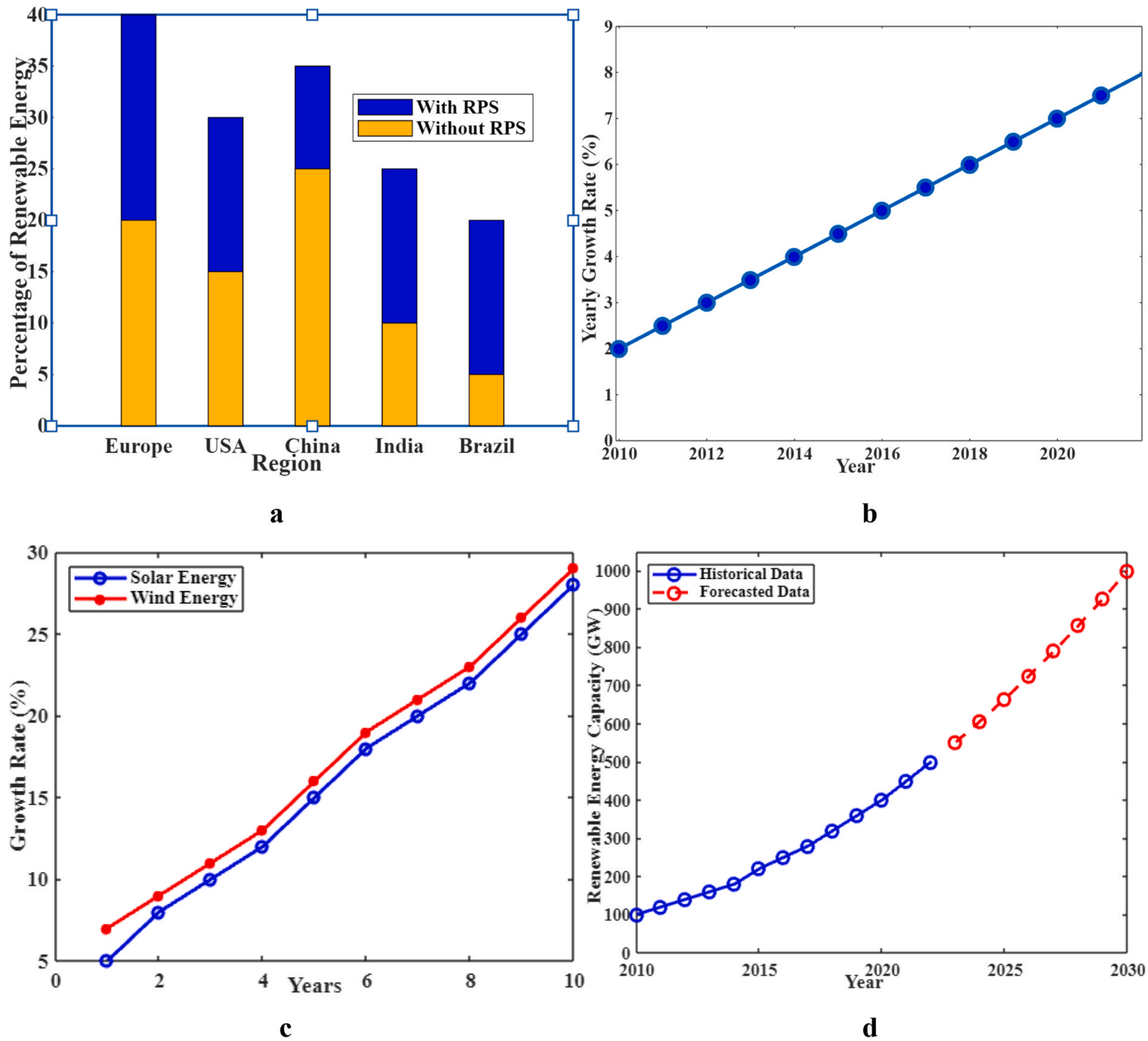

Fig. 9. (a) Effectiveness of renewable portfolio standards across the world (b) yearly growth rate of wind energy production in Germany (c)Comparative Growth Analysis of Solar and Wind Energy (d) Forecasting Renewable Energy Trends Based on Current Policies.

policymakers and stakeholders to base their strategic decisions.

6. Policy implications and recommendations

The NZT provides key insights for policymakers, industry leaders, and stakeholders to enhance renewable energy policies and better use data-driven tools. Fig. 8 outlines recommendations to optimise policy frameworks, improve tracking tool use, and boost sustainability outcomes.

6.1. Recommendations for enhancing renewable energy policies

Strengthen and Harmonize Policy Incentives by Align incentives like feed-in tariffs, tax breaks, and subsidies to encourage renewable energy investments. Inconsistent regional policies can lead to uneven results. International agreements should establish baseline standards. Update Regulatory Frameworks by Simplify and modernise regulations to integrate renewable technologies and support energy storage. Engage industry stakeholders to address concerns and ensure smoother transitions [64,65]. Promote Public-Private Partnerships by fostering collaborations between governments and private companies to finance renewable projects, especially in underdeveloped regions [65,66]. Governments can offer guarantees or co-invest to reduce risks and attract private investment. These recommendations aim to create cohesive, effective renewable energy policies.

6.2. Strategies for improving the use of the NZT in policy-making

The NZT should be integrated directly into national energy systems to provide real-time data for informed decision-making. This requires technical compatibility and stakeholder engagement. Standardized data formats, interfaces, and workshops can demonstrate the benefits. Regular Updates and Customization of the tracker must be regularly updated with new data and features to stay relevant. Ongoing maintenance can be resource-intensive, so dedicated budgets and partnerships with tech providers are essential for sustained support [67,68]. Training and capacity building provides training programs for policymakers and analysts to use the tracker effectively. Online training resources and regional hubs can help address limited technical expertise in certain regions.

6.3. Long-term impacts on sustainability goals

Global Energy Transition is implementing these strategies can

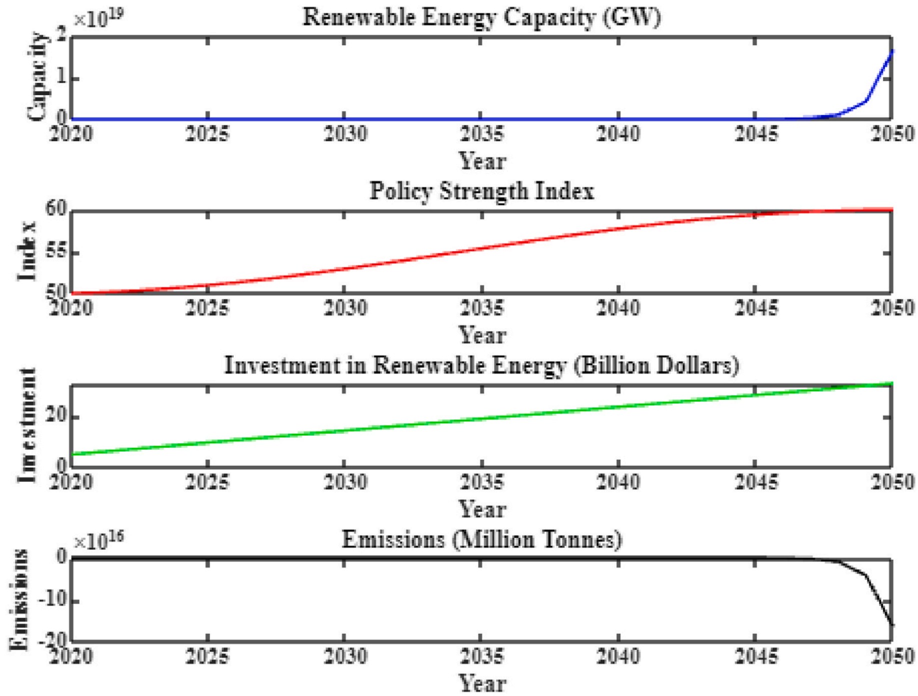

Fig. 10. Projected trends in renewable energy capacity, policy strength, investment, and emissions reduction towards 2050.

accelerate the global shift to renewable energy, reducing carbon emissions and enhancing energy security. Economic Growth and Job Creation recommendations will foster economic growth and create jobs in the green energy sector by encouraging renewable energy investments. Enhanced International Cooperation is harmonizing policies and sharing tools like the NZT, which can strengthen international collaboration, driving a coordinated approach to achieving global sustainability goals [68,69]. Fig. 8(a–d) illustrates global renewable energy capacity trends from 2010 to 2025, showing growth across categories like hydro, wind, and solar PV, offering a colourful visual representation of renewable energy expansion.

Fig. 9 illustrates the impact of renewable portfolio standards (RPS) and the growth of renewable energy globally. Fig. 9(a) compares renewable energy percentages in regions like Europe, USA, China, India, and Brazil with and without RPS. Blue bars show regions with RPS have higher renewable energy adoption than those without (orange bars), demonstrating the effectiveness of RPS. Fig. 9(b) shows Germany's wind energy production growth from 2010 to 2020, with a steady upward trend, highlighting the success of its policies and investments. Fig. 9(c) compares growth rates of solar (blue) and wind (red) energy over ten years, showing consistent increases, with wind energy slightly outpacing solar. Fig. 9(d) presents historical (blue) and forecasted (red) renewable energy capacity from 2010 to 2030, showing a steady increase in both, indicating future solid growth. These Fig. 9(a–d) highlight the positive effect of policies like RPS on renewable energy adoption and growth, offering strong evidence for policymakers to replicate similar strategies globally.

Fig. 10 presents four subgraphs projecting trends from 2020 to 2050. The renewable energy capacity graph shows an exponential increase starting around 2045, indicating a major shift or widespread adoption of renewable technologies aligned with global net-zero goals. The Policy Strength Index (PSI) rises gradually from 50 in 2020 to 60 by 2050, reflecting continuous policy improvements supporting renewable energy and emission reductions. Investment in renewable energy will grow steadily from \$10 billion in 2020 to nearly \$25 billion by 2050, signaling increased financial commitment crucial for capacity expansion. Emissions, shown in million tonnes, will steadily decrease to zero by 2050, illustrating the impact of more robust policies and investments in reducing greenhouse gases. Fig. 10 highlights the interconnected relationships between renewable energy growth, policy enhancement, investment increases, and emission reductions over the next three decades. The novelty of this model lies in its comprehensive approach, integrating key factors to offer a clear roadmap toward achieving net-zero emissions. These projections provide valuable insights for policymakers, investors, and stakeholders to make informed decisions and accelerate the shift to a sustainable energy future.

7. Conclusion

In conclusion, this study introduces a novel system dynamics model that quantitatively evaluates the interdependencies between policy strength, investment, renewable energy capacity, and emissions reductions. Through recursive equations, the research captured the dynamic nature of policy and the economic factors that influence the growth of renewable energy sectors. The model incorporates a sinusoidal function to simulate the periodic nature of policy changes, reflecting real-world fluctuations due to political and economic cycles.

The results indicate that a consistent increase in the policy strength index by 10 % annually can enhance renewable energy capacity growth by approximately 15 % year-over-year while reducing CO_2 emissions by up to 20 % from the baseline by 2030, assuming all other factors remain constant. This demonstrates the potential of targeted policy measures in accelerating the transition to renewable energy.

Moreover, the investment dynamics equation highlighted the critical role of sustained investments, showing that a decrease in investment decay rate by 0.01 units could retain an additional 5 % of investment from the previous year, further boosting capacity expansion and emissions reduction. However, the model also revealed sensitivity to parameter changes, where minor variations in the policy influence coefficient (γ) led to substantial differences in projected outcomes, suggesting areas for further refinement. These findings underscore the utility of the NZT in providing policymakers and stakeholders with a robust analytical tool to forecast the impacts of their decisions and optimise strategies for a sustainable future. The model's ability to adapt to varying inputs and produce quantifiable outputs makes it an invaluable asset in achieving NZE globally.

CRediT authorship contribution statement

Bankole I. Oladapo: Project administration, Validation, Writing – review & editing, Supervision, Writing – review & editing, Visualization, Writing – review & editing, acquisition. **Mattew A. Olawumi:** Conceptualization, Methodology, Software, Writing – original draft, Validation, Visualization, Investigation, Writing – review & editing, Funding acquisition, Resources. **Temitope Olumide Olugbade:** Conceptualization, Methodology, Software, Writing – original draft, Validation, Visualization, Investigation, Writing – review & editing. **Sikiru O. Ismail:** Visualization, Investigation, Writing – review & editing, Funding acquisition, Resources.

Ethical statement

The authors declare no ethical issue; the study was conducted entirely with ethical standards. Also, the manuscript is neither under review nor published elsewhere.

Declaration of competing interest

The authors declare that they have no known competing for financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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