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Factors influencing the transition to renewable energy in small- to mid-sized American communities

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Abstract

Background The transition to renewable energy is essential for addressing climate change and fostering sustainable communities. This involves planning and determining where, when, and how to deploy renewable energy technologies. This requires supportive policies and regulations to accommodate renewable energy sources and manage impact, as well as engagement with local communities and stakeholders to secure their support and participation in the transition process.

Methods This study evaluates the impact of governance at various levels—community, county, and state—on renewable energy adoption in 87 small- to mid-sized U.S. communities with populations below 100,000. Using a multi-faceted analytical approach, this research reviews comprehensive climate action and sustainable plans to identify key drivers of renewable energy transitions. This study explores whether local government plans and multi-level governance efforts enhance renewable energy adoption in these communities. By examining the integrated policy approach, this research explores the interplay between governance levels and their collective impact on renewable energy consumption through regression and comprehensive content analysis.

Results Content analysis of 134 reviewed community, county, and state plans revealed that local governments adopt renewable energy targets in their local plans less frequently than state and county governments do. Among the 87 communities studied, 63% implemented limited renewable energy consumption, with percentages ranging from 5 to 30%. In contrast, only four communities (5%) achieved full renewable energy dominance with 100% renewable energy consumption. Regression analysis identified four significant factors influencing renewable energy consumption percentages: building energy efficiency measures at the community level, sustainable land use promotion at the county level, renewable energy targets, and sustainable land use frameworks at the state level.

Conclusions This study underscores the significance of a multi-level governance approach in facilitating local energy transitions, noting that successful implementation relies on efforts from local governments. It stresses the need for integrated policy frameworks that synchronize state, county, and local actions to develop supportive policies and regulations for effective land use planning, energy efficiency measures, and community engagement to achieve renewable energy targets more effectively.

Keywords Renewable energy transition, Governance, Community engagement, Sustainable land use, Multi-level governance

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Background

Energy provision is a fundamental service for modern societies and has significant implications for economies, cultures, and environments [1]. Transitioning to renewable energy sources requires efforts and coordination at multiple governance levels and is crucial for building sustainable futures for communities [2]. Changes in land use, energy consumption, built environmental practices, and urban and rural planning accompany this transition. These changes necessitate substantial investments, changes in public behavior and practices, as well as strategic planning to address and manage the environmental, social, and economic impact of this transition [3]. Planning for energy transitions involves determining where, when, and how to deploy and locate renewable energy technologies. This involves policies and regulations to manage these impacts, as well as engaging with local communities and stakeholders to secure their support and participation in the transition process [4].

Local governments play an essential role in supporting the energy transition through their planning and policymaking powers, and can influence the pace and direction of energy transitions [5]. These plans shape the spatial distribution of renewable energy systems, regulate their operation and impacts, and facilitate their integration into local energy markets and infrastructures. However, planning for the energy transition is a complex and challenging task that involves technical, economic, social, political, institutional, and environmental dimensions [6, 7]. Engaging with local communities is a critical aspect of the energy transition process because it promotes a sense of ownership and facilitates knowledge sharing [8].

This research evaluates the adoption and implementation of energy transitions at various governance levels––community, county, and state––in 87 communities that increased their renewable energy share and made progress toward a renewable energy transition. This study examines how communities incorporate elements such as building energy efficiency, renewable energy targets or goals, renewable energy siting, sustainable land use, and energy incentives within their development plans and policies at each governance level. This study seeks to determine whether integrating these elements at the initial stages within development plans can effectively influence the energy transition. Furthermore, the research examines how interactions across multiple governance levels (community, county, and state) support low-density communities in transitioning to renewable energy.

Multi-level governance and renewable energy transition

Multi-level governance (MLG) is critical for successfully implementing energy transition strategies. This involves coordination and collaboration between different levels of government, including local, regional, national, and sometimes international, to achieve energy transition goals [2, 6]. Effective MLG facilitates resource and knowledge sharing, encourages innovation and enhances the scalability and replicability of successful initiatives [9]. The decentralized federalism model in the U.S. allows top-down directives and lower-level operations that create opportunities for innovative carbon reduction approaches in the energy sector. However, without coordination, this may result in slower, fragmented efforts [10, 11].

Local political leaders influence the acceptance of renewable energy systems, but the literature lacks comprehensive studies on how these influences vary across governance levels. For instance, Azarova et al. [12] found that local political support can increase acceptance, but this has not been uniformly studied across different governance contexts. Moreover, policy instability and the contradiction between fossil fuel supporters and renewables advocates can create inconsistencies in policy development, even within the same state, affecting investment decisions, project permitting, and transition dynamics [13]. For instance, the misalignment between state and county decision-making can lead to prioritizing short-term economic gain from oil and gas industries over long-term environmental sustainability, causing conflict between the two governance levels and leading to a lack of cohesive strategy for addressing climate change [14]. In a study by Graff, Carley and Konisky [15] the authors highlighted that stakeholders' perceptions vary among regions, and are linked to economic concerns such as job loss, rising energy costs, and communities' ability to adapt. While these studies emphasize the need for collaboration between national, state, and local stakeholders to respond to the energy transition, they remain theoretical and do not delve into pathways to address community opposition.

Multi-level energy transition in the United States

The energy sector in the United States is complex and characterized by the involvement of numerous stakeholders operating at various levels, all of whom influence energy policies and decision-making processes. The U.S. energy policy is marked by periods of surplus, shortages, and deregulation, and calls for comprehensive policies that reflect the ongoing struggle to balance economic, environmental, and security concerns [16]. The transition toward renewable energy sources, such as solar and wind, introduces additional regulatory and governance challenges as various actors, including utilities, regulatory agencies, and consumer advocacy groups, affect incentives and regulatory frameworks [17].

The federal government has the authority to regulate interstate transmission, interconnection, trade, and infrastructure, and the states have the actual authority over transmission developed within their territories [18]. While states have the authority to the local jurisdiction to shape land use, municipal authorities dominate decision-making on what can be constructed, how, and where under state-adopted zoning ordinances, subdivision rules, traffic standards, building design requirements, adopted building codes, and local rules [19]. This situation poses challenges for progressive municipalities aiming to address climate change in states that do not prioritize environmental issues, where residents can easily revert to state jurisdiction, complicating local efforts [20]. Additionally, zoning and planning regulations are often different from one municipality to another, affecting the adoption of innovative solutions at the state level [21].

Energy transition at national level

The Inflation Reduction Act (IRA) of 2022 signifies the largest federal investment in climate mitigation and clean energy in U.S. history, with $369 billion dedicated to clean energy technology manufacturing, development, and usage, along with tax incentives for electrifying transportation and other sectors. [22]. While the IRA marks a historic step in the U.S. climate policies by focusing on incentives and tax credits, it remains limited in achieving a comprehensive energy transition with the absence of binding regulations and reliance on market-driven solutions that may not suffice to promote the energy transition needed to meet climate goals [23, 24]. Thus, the effectiveness of the IRA or other federal policies can vary based on the capacity and willingness of states that may either adopt or reject renewable energy [25]. Although financial, technological, and market factors affect the adoption of renewable energy, federal support comes in a one-size-fits-all approach that overlooks local specificities that can yield undesirable outcomes [26]. For instance, rural communities typically have more access to land and specific resources [27] sufficient for renewable energy systems [28], but have fewer economic opportunities and capital, less population, and modern energy infrastructure than urban areas, which may require different strategies than urban areas tailored to the local context to be effective [29, 30].

Energy transition at state level

Many states have adopted various strategies to facilitate a renewable energy transition, increase energy efficiency, and develop energy infrastructure projects [31]. Renewable portfolio standards (RPS) and feed-in tariffs (FIT) are among the most common state initiatives used to promote a renewable energy transition [32]. RPS requires utilities to source a certain percentage of their electricity from renewable sources [33], whereas FIT guarantees a fixed price [34]. Both initiatives focus on the macro level, often neglecting the micro-level impact of local communities. For example, the tension is evident in the state of California, where local communities affected by utility-scale renewable energy projects struggle to have their concerns addressed in state-level frameworks that overlook local impacts and voices [35].

Building energy efficiency has been recognized as a major factor in reducing energy consumption [36]. Federal incentives and state-level policies have been implemented to promote energy efficiency [37], and building energy codes have been adopted by states to set minimum energy efficiency standards for new construction or renovated buildings [38]. However, progress remains slow due to reliance on voluntary measures, such as rebates and voluntary energy efficiency targets [39]. On the other hand, the effectiveness of energy efficiency policies can vary widely among states due to differences in regulatory environments, economic conditions, and political priorities. Some states have minimal and weak regulatory frameworks, leaving local authorities with limited power to impose stricter measures [40, 41].

Energy transition at county and municipal levels

Energy transitions at the county or municipal level are often tasked with managing and achieving local energy reduction goals by reducing energy consumption in buildings and addressing local challenges. Community energy initiatives have increased at the local level to enhance energy security, reduce costs, promote environmental sustainability, and ensure coordinated efforts [42]. However, with the growing role of local communities and energy decentralization, more focus is needed to address spatial planning and economic benefits [5]. Traditional land use planning is detached from renewable energy needs, and the literature often focuses on general land use allocation and zoning, such as specific uses and environmental impacts [43]. The detachment results in a lack of comprehensive sustainable plans that specify suitable renewable energy zones, leaving energy projects struggling with permitting processes and community opposition. Lamhamedi and de Vries [44] also highlighted the lack of connection between land use and energy production in policy debates, which could lead to land pressures and uneven development patterns. However, it does not discuss strategies to address land use conflicts and optimize spatial planning.

Prior research has also focused on the role of multiple factors that affect the transition to renewable energy. For example, Wu and Lui [45], Paul et al. [46], Basir et al.

[47] emphasized on the role of building energy efficiency in reducing energy demand and increasing renewable energy consumption. Research also suggests that adopting renewable energy targets is essential for sustainable policies [48]. However, this requires support from higher governance levels [49]. Conversely, Kellett [50] emphasized on the benefits of rooftop solar energy to promote energy self-sufficiency and reduce reliance on fossil fuels. Goel et al. [51] underlined the impact of incorporating renewable energy siting and rooftop solar energy in urban planning would lead to substantial environmental and economic benefits, whereas Gerundo and Marra [52] suggested that this integration can encourage citizens to welcome renewable energy sources and deployment of renewable energy. Guo et al. [53] discussed the importance of integrating sustainable land uses like smart growth or transient-oriented planning to limit sprawl and identify suitable lands for renewable energy, while Sarzynski [54], Kaplan [55] confirmed the importance of financial incentives in increasing renewable energy adoption at county and municipal levels by providing opportunities for communities and developers.

Energy transition as a part of local development plans

Local development plans, such as comprehensive, sustainability, and climate action plans, play an essential role in shaping communities' growth and development. These plans vary in scope and time frame. Comprehensive plans are typically developed for long term and address all aspects of community development including land use, transportation, housing, and infrastructure [56, 57]; sustainability planning focuses on balancing economic, social, and environmental objectives for local development, typically consisting of specific goals, indicators to measure progress to meet these goals, and targets for indicators [58, 59]; and climate action plans are more targeted toward strategies and measures to address greenhouse gas emissions, build more resiliency, and adapt to climate change impacts [60, 61]. Despite these differences, these plans outline visions, objectives, goals, and actions to promote sustainable growth and enhance residents' quality [62, 63]. Each plan reflects the communities' unique needs and aspirations and ensures that development is aligned with local priorities [63]. These local development plans are usually translated into policies and regulations that incentivize plan development while reflecting on political and institutional contexts, power relations, and the interests and values of stakeholders involved in the process [62].

To date, most investigations on energy transition planning have focused on one aspect when integrating energy planning with land use. Guo et al. [53], Vernon et al. [64], Lopez et al. [65], and Lange [66] focused on the technical potential of renewable energy, whereas Hess and Gentry [67], Tsoeu-Ntokoane et al. [68], Romero-Lankao [69], Hindmarsh and Matthews [70], and Watson [71] focused on community engagement to foster acceptance and address opposition to renewable energy projects. Susskind et al. [72] highlighted the importance of early engagement with local community members during planning and impact assessment stages. However, these studies focused on specific projects rather than a broader local transition where a comprehensive approach is needed to facilitate a community-wide transition through broad dialogue about local energy goals, support infrastructure changes, mitigate land use conflicts, and provide long-term benefits.

The coordination process among multiple government levels is complex, non-linear, and interactive [73]. Communication among all these levels, in addition to communicating plans and targets with community members, relies on expectations that require meeting community needs and future development that are in line with national and state objectives to decarbonize the energy sector [74]. The early adoption of renewable energy transition in local plans plays a crucial role in addressing energy sprawl and fostering community acceptance of sustainable energy initiatives [54, 75]. This integration ensures that renewable energy sources are considered from the initial stages of development. It also helps create a long-term vision for sustainable energy practices, which aligns development goals with environmental objectives. Our study offers a multi-level understanding of the impact of integrating planning for energy transitions within local development plans by understanding common trends in local plans, proposing that these plans offer a stage to foster acceptance and address opposition through their long-term process of development. In addition to reporting on the notable patterns across the 87 sampled communities, we attempt to draw lessons that provide a perspective on multi-level governance interactions in addressing five key variables that affect energy transition.

Methods

The current study evaluates the impact of various governance plans and strategies on the renewable energy transition in the United States. By focusing on different levels of governance, this study examines how both comprehensive and specific plans––such as general plans, climate action plans, and sustainable plans––contribute to increasing the share of renewable energy in total energy consumption. This research aims to identify key drivers of renewable energy adoption through regression analysis and comprehensive content review. It provides a thorough comparison of plans that are fully committed to renewable energy versus those that merely promote it. The interaction between local, county, and state plans is also investigated to understand how different governance levels shape renewable energy dynamics at the regional level. This study focuses on small to mid-sized local communities with populations under 100,000, as these communities tend to have a stronger sense of community and shared responsibility. Engaging them in the early stages can significantly facilitate or hinder the energy transition [76]. These communities have a local governmental authority that manages essential public services and develops plans and regulations. Figure 1 presents the distribution of the 87 communities included in this study.

Community selection

The list of communities identified was through web searches, environmental advocacy organizations, and governmental agencies that publicly announced and published information on their transition to renewable energy, including a list of communities that embarked on their journey toward RE through participating in programs with governmental or non-profit agencies. The Environmental Protection Agency (EPA), a federal agency that has a green power community, is a voluntary program that tracks communities' green power percentage of the total electricity use; of the 122 communities recognized by the program, 105 were listed [77] and included in this study. On the other hand, Sierra Club, an environmental advocacy agency, has a ready 100 campaigns that were last updated in 2022 which include powered cities, committed communities, and campaigns in cities to transition to renewable energy; among this list, 51 cities and counties were identified [78] and included in this study. Additionally, the local energy action program (LEAP), funded by the Department of Energy, a federal agency, and operated by the National Renewable Energy Lab (NREL) a national lab, aims to support low-income, energy-burdened communities willing to transition to renewable energy; the communities engaged in this program varied from towns to tribal communities, among which 14 communities were identified and selected based on their primary goals of clean energy and energy efficiency, clean energy planning and deployment or community resilience microgrid, and energy storage [79]. An additional 17 communities were identified through Google search. From these four diverse sources, 187 potential communities were identified, and six duplicate communities were removed. To leave us with 181 communities. Detailed information was collected on the population, developed plans, and renewable energy percentage as a total of the total electricity use. The sample was narrowed down to include communities below 100,000 in population, with at least one plan developed or updated after 2005, a significant year for energy

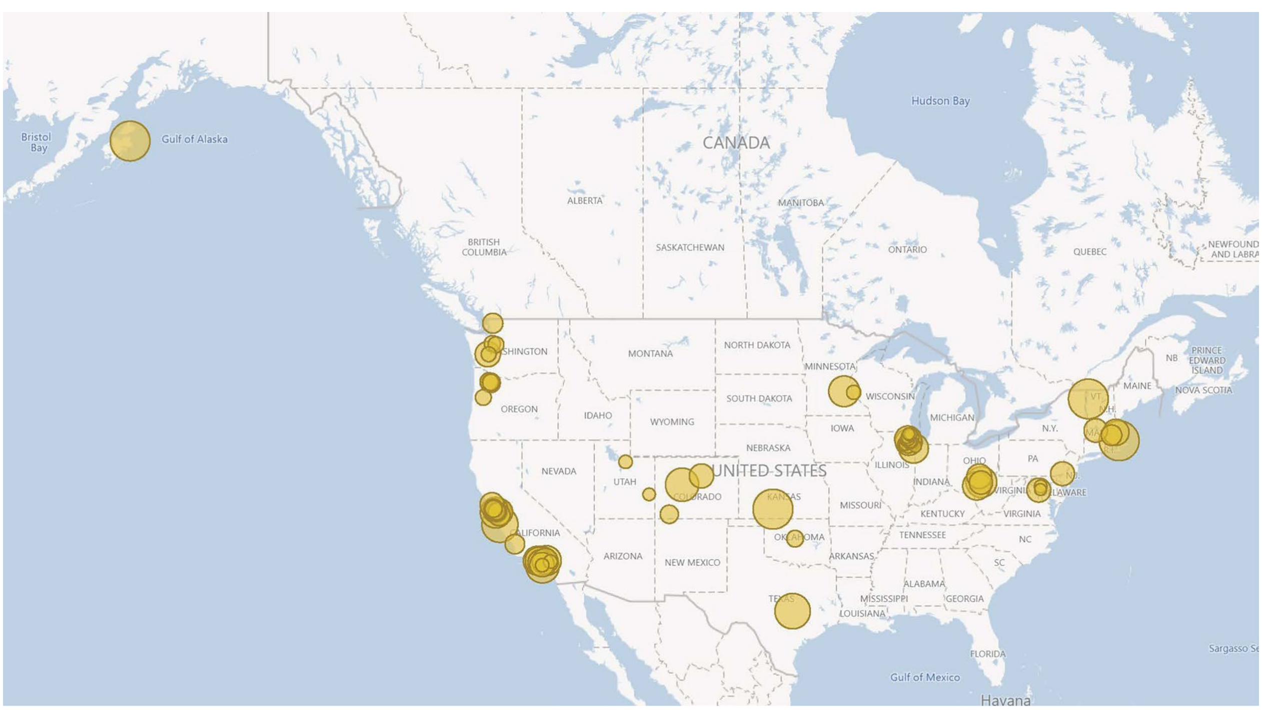

Fig. 1 Distribution of communities transitioning to renewable energy across the US––a subset of communities identified based on research selection criteria and their renewable energy consumption percentage as a share of total electricity use

policies in the United States and clean technologies commercialization [54], where the US Energy Policy Act of 2005 aimed to achieve energy self-sufficiency by 2025 and included incentives for electricity generation from renewable sources [80]. The plans included comprehensive/general plans, climate action, and sustainable plans. The final number of communities included in this study was 87. Figure 2 outlines the identification and selection criteria of the communities.

For each of these eighty-seven communities, counties and states were identified. The 87 communities were in 18 different states and 39 counties. For each state and county, a detailed search was conducted to identify published long-term and short-term plans, as well as building energy efficiency regulations, siting regulations, and zoning ordinances, to identify specific renewable energy siting or co-location regulations [81, 82]. The detailed review allowed analysis at the three different governance levels.

Evaluation method

Content analysis, as a qualitative method, has been used in urban planning to gather data, field notes, and plans on development issues [83, 84]. This method uses coding to reflect on identified themes, and then categories identified are either predefined based on theoretical concepts or inductively emerge from the data itself [85]. This approach allows planners to balance conflicting objectives by assigning weights to different criteria. This is similar to the method used by Temur et al. [86] where scoring is used to weigh interactions based on their importance to sustainability. In the study by Mark et al. [87], which used a multi-attribute evaluation approach to develop weighing schemes and assigned unequal weights to plan items based on their importance to improve plan quality evaluation. However, the scales of these scores varied across studies, studies by Brody [88, 89] used a 0–10 scale, Breke et al. [90] used a 0–100 scale, and other studies included multiple items and computed an overall mean proportionate score [91].

In this study, we conducted a content analysis of community plans followed by an evaluation criterion to assess how each plan addressed the renewable energy transition. This involved manually reviewing 134 distinct plans for 87 communities. The initial step was to categorize the documents based on the type of plan. Then, each document was reviewed through a standardized process including skimming and scanning to develop a common understanding of its content and subsections. Subsequently, we developed a coding manual to ensure consistency and reliability of the data, as well as to outline how information would be collected and recorded. The manual comprises five indicators selected to guide the analysis and keywords that direct the search. These

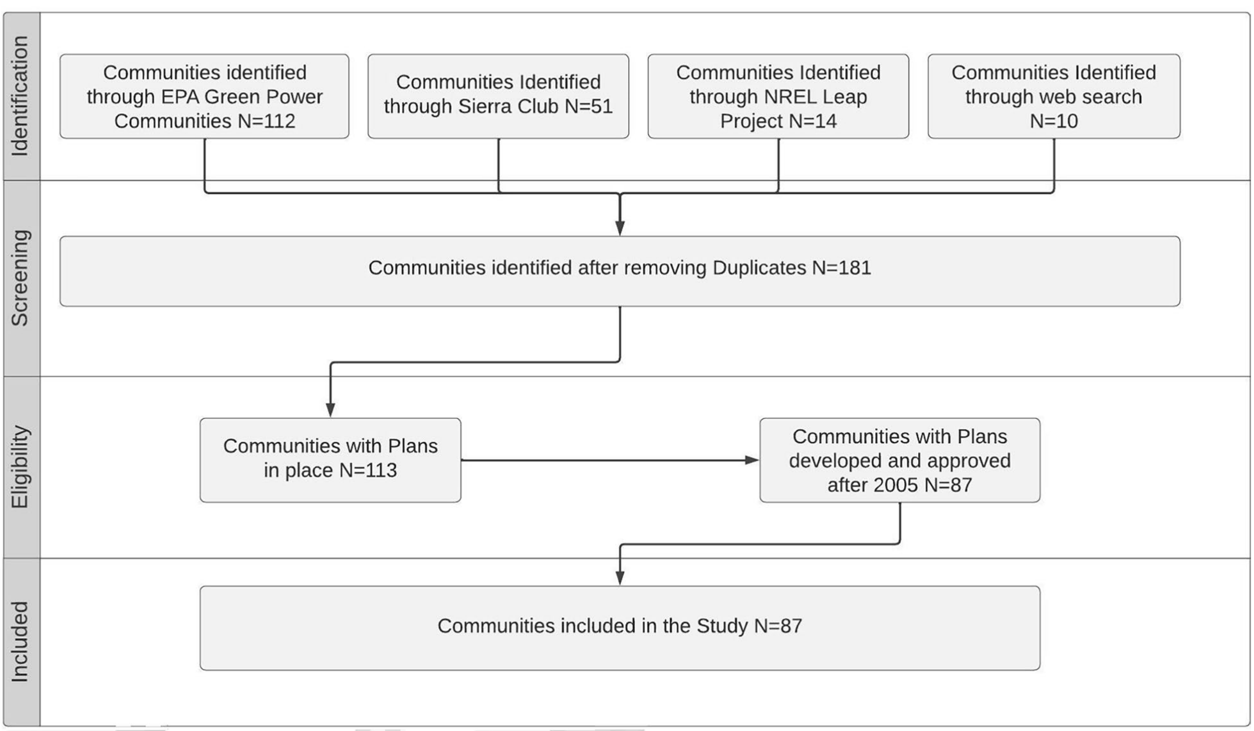

Fig. 2 Community selection criteria

keywords included terms such as renewable energy, transition, solar, wind, geothermal, biogas, biomass, rooftop, siting, ordinance, sustainable land use, transit-oriented, smart growth, co-location, agrivoltaics, energy efficiency, weatherization, passive house, net zero, climate change, energy targets, sustainable targets, and incentives. The keywords guided the detailed review of subsections within the plans to determine whether these plans adopted building energy efficiency, included specific renewable energy targets or goals, developed renewable energy siting or co-location including rooftop solar, promoted sustainable land use, and provided energy incentives, as well as the level of adoption. The review also included a search of local authorities' websites to identify whether they had established policies or regulations to implement energy efficiency and renewable energy placement. The findings from the review were documented and tabulated in the form of short sentences highlighting the keywords in each cell to facilitate scoring.

Scoring criteria

Content analysis was followed by a weighted scoring system. For each criterion, a set of themes was identified, and a score was assigned based on the extent to which each theme was addressed in the community plans. Scores ranged from 0 to 5 (Annex––Scoring System), with 5 indicating a high level of commitment, facilitation, or significance in contributing to the energy transition. This method allowed for a comparison of communities' approaches to energy transition in those plans and facilitated understanding standard practices among communities with higher renewable energy percentages.

Themes that received a score of 5 demonstrated the highest commitment and impact among the factors selected through policies and regulations. For example, communities that have set ambitious goals to achieve 100% renewable energy by a specific year or established comprehensive zoning ordinances for renewable energy siting earned a score of 5. A score of 4 was awarded to themes that showed a strong commitment but lacked the comprehensiveness or ambition of those scoring 5. For instance, communities with incremental renewable energy goals, those encouraging sustainable land use without enforcement, or communities adopting energy efficiency requirements that do not extend beyond building codes all scored 4.

Themes that received a score of 3 involved significant efforts to promote energy efficiency or facilitate renewable energy adoption or installation. A score of 2 was assigned to themes that promoted one of the variables in their plans, primarily through encouragement and promotion; these efforts increased awareness but were less impactful than mandatory requirements. Themes that scored 1 reflected minimal efforts to promote one of the variables, limited in scale or across sectors, including promoting mixed land use in a specific area or land preservation within one sector. Finally, a score of 0 was given to themes with no efforts or specific policies addressing renewable energy, energy efficiency, or sustainability within the energy transition.

The bar graphs in Fig. 3 summarize the main findings across all types of community plans identified, along with county and state policies, plans, and regulations governing the five identified variables. The distinct colors in the graphs represent the number of plans that received scores of 0, 1, 2, 3, 4, or 5 for each variable.

Multi-level governance multiple regression analysis

This study analyzes the role of effective governance structures in facilitating a successful energy transition. Effective governance structures are vital for implementing these plans, ensuring coordination among stakeholders, allocating resources, and maintaining regulatory compliance to achieve a successful energy transition [92]. The multi-level governance framework has evolved to address the overlapping and dispersion of authorities across various jurisdictions [93], the management of public affairs, and the development and implementation of policies [94]. Through policy alignment, the framework provides a structured approach to analyzing whether stakeholders involved in local development influence the transition to renewable energy. Multiple studies have employed regression analysis to examine the renewable energy transition. While economic and social factors, such as community income levels, affect the initial adoption of these strategies by influencing access to financial resources, investment incentives, and public engagement (Topçu and Türgüt [95]; Fazal et al. [96]), their significance diminishes when evaluating the success of implementation in communities that have already adopted an energy transition plan. Higher-income communities often have the financial means to adopt renewable energy solutions more easily, whereas lower-income areas need external support mechanisms, such as subsidies and policy interventions, to facilitate adoption (Setyadharma et al. [97]). Our study specifically examines communities that have already begun energy transition plans and seeks to identify the key governance factors that contribute to their effective execution. Therefore, including income as a control variable would conflate determinants of adoption with factors influencing implementation. Our regression analysis emphasizes governance structures at multiple levels, allowing us to investigate the mechanisms that support the sustained and successful deployment of renewable energy policies (Kunkel et al. [98]; Vaishnav [99]).

Fig. 3 Distribution of variables across all three governance levels (Community, County State)

Kunkel et al. [100] analyzed the adoption and implementation of RE policies in U.S. cities using regression analysis. Although regression analysis provides valuable insights into renewable energy transition, it is important to consider the limitations and uncertainties in quantitative analysis. Vaishnav [101] argues that quantitative policy analysis must be part of broader qualitative considerations to navigate the complexities of the energy transition. We adopt a multi-method approach to analyze the collected data and to understand the factors influencing the transition to renewable energy consumption. The analysis focused on identifying the levels at which components impacting the transition to RE can be initiated and how state and county levels can better support local governments. To achieve these objectives, this study employed a combination of regression, statistical, and comprehensive content analysis of the collected data to draw conclusions. A comparative analysis complemented this, where the findings were compared across different governance levels (state, county, and local) to draw meaningful insights and lessons from the analysis. Table 1 summarizes the themes from the previous section at the community, county, and state levels, respectively, and the abbreviations used in our analysis of the data in the following sections.

The regression model employed in this study evaluates the influence of individual indicators on the percentage of renewable energy consumption relative to total electricity consumption for each community at three governance levels: local, county, and state. Drawing from previous research, including studies by Kunkel et al. [100] and Vaishnav [101], this linear regression model allows for straightforward estimation and interpretation of how governance factors impact renewable energy transitions. Multi-level governance theory supports this approach by recognizing the interaction between different governance levels in shaping renewable energy policies and outcomes. The independent variables––such as building

Table 1 Summary of themes, regression variables, abbreviations, and level of data

Abbreviation	Theme	Type	Level
REC	Renewable Energy Consumption Percentage	Dependent	Community
CME	Building Energy Efficiency	Independent	Community
CMT	Specific Renewable Energy Targets	Independent	
CMS	Renewable Energy Siting and Co-Location	Independent	
CMP	Promoting Sustainable Land Use	Independent	
CMI	Renewable Energy Incentives	Independent	
STE	Building Energy Efficiency	Independent	State
STT	Specific Renewable Energy Targets	Independent	
STS	Renewable Energy Siting and Co-Location	Independent	
STP	Promoting Sustainable Land Use	Independent	
STI	Renewable Energy Incentives	Excluded	
CNE	Building Energy Efficiency	Independent	County
CNT	Specific Renewable Energy Targets	Independent	
CNS	Renewable Energy Siting and Co-Location	Independent	
CNP	Promoting Sustainable Land Use	Independent	
CNI	Renewable Energy Incentives	Independent	

STI is excluded from the regression analysis because there is no variability in the data across selected communities in our study

energy efficiency, renewable energy targets, and sustainable land use promotion−−were selected for their demonstrated significance in the literature and their relevance to small community governance structures (e.g., Attanayake et al. [102]). These insights are critical for informing future long- and short-term energy planning and highlight the importance of policy alignment and coordinated action to engage communities and encourage renewable energy adoption at the local level.

Regression analysis equation:

$$REC = \beta_0 + \beta_1 CME + \beta_2 CMT + \beta_3 CMS + \beta_4 CMP + \beta_5 CMI + \beta_6 CNE + \beta_7 CNT + \beta_8 CNS + \beta_9 CNP + \beta_{10} CNI + \beta_{11} STE + \beta_{12} STT + \beta_{13} STS + \beta_{14} STP + \varepsilon, \quad (1)$$

where REC is the dependent variable and represents the percentage of energy generated in each community from renewable sources; *CME, CMT, CMS, CMP, CMI, STE, STT, STS, STP, STI, CNE, CNT, CNS, CNP, and CNI* are treated as continuous independent variables representing the indicators and their respective levels. ϵ is an error term accounting for the variability of REC that cannot be explained by independent variables.

The regression Eq. (1) represents a full model that includes all relevant predictors expected to have a significant correlation to the dependent variable. We also used a nested, backward stepwise regression, where variables are strategically removed in order of least significant contribution to the overall model fit or explanatory power. At each "step" in this method, variables are removed to identify a simplified model that best explains the data. The best model according to these criteria was found after eleven steps and is represented and described in Eq. (2)

$$REC = \beta_0 + \beta_1 CME + \beta_2 CMP + \beta_3 STT + \beta_4 STP + \varepsilon. \quad (2)$$

Additionally, in each model described in Eqs. (1) and (2), multicollinearity was tested using the Variance Inflation Factor (VIF), with all values below 5, confirming that multicollinearity does not pose an issue in this analysis by James et al. [103]. The results of the multicollinearity tests have been added to the Results section.

Governance factors, such as building energy efficiency policies and renewable energy targets, have been shown to significantly influence renewable energy adoption. Drawing on these insights and multi-level governance theory, we developed the following hypotheses to guide our examination of the relationship between governance structures and renewable energy consumption, which are stated in their alternative hypothesis form. While prior research suggests a relationship between governance policies and renewable energy adoption, the directionality of these effects may depend on contextual factors such as policy design, enforcement mechanisms, and interactions with other policies. Given this complexity, our hypotheses remain neutral regarding the direction of influence, allowing for an empirical assessment of both positive and negative effects:

H$_1$

Communities with higher levels of building energy efficiency policies exhibit higher percentages of renewable energy consumption than those without such policies. This is based on established findings in the literature that energy efficiency policies significantly contribute to the adoption of renewable energy sources.

H$_2$

Communities with specific renewable energy targets integrated into their local development plans will show a greater percentage of renewable energy consumption.

Results

Statistical analysis

The distribution of renewable energy consumption percentage as a share of the total electricity use across the 87 communities varied, as did the adoption of each of the five variables across each level. Figure 4 shows the distribution of renewable energy consumption percentage across 87 communities. The diagram highlights the adoption of the five energy-related variables examined in this research at three governance levels, local, county, and state. Each dot represents the score of these variables for each community, allowing for comprehensive visualization and comparison across all levels.

Across the 87 communities identified, 134 plans were identified. Most communities had a comprehensive plan in place, and 44 had more than one plan. Many of the communities, 55 (representing 63%), have a limited renewable energy consumption percentage, with their total energy consumption ranging between 5 and 30% (Fig. 5). Additionally, 18 communities (21%) showed a moderate mix, with adoption rates between 30 and 50%. Nine communities (10%) have demonstrated significant transition progress, with rates varying between 50 and 80%. Four communities (5%) achieved renewable energy dominance, with 100% renewable energy consumption. Only one community showed minimal transition, with rates below 5% (Fig. 6).

Regression analysis

The regression analysis results showed that at the community level, building energy efficiency has a significant positive impact on renewable energy consumption

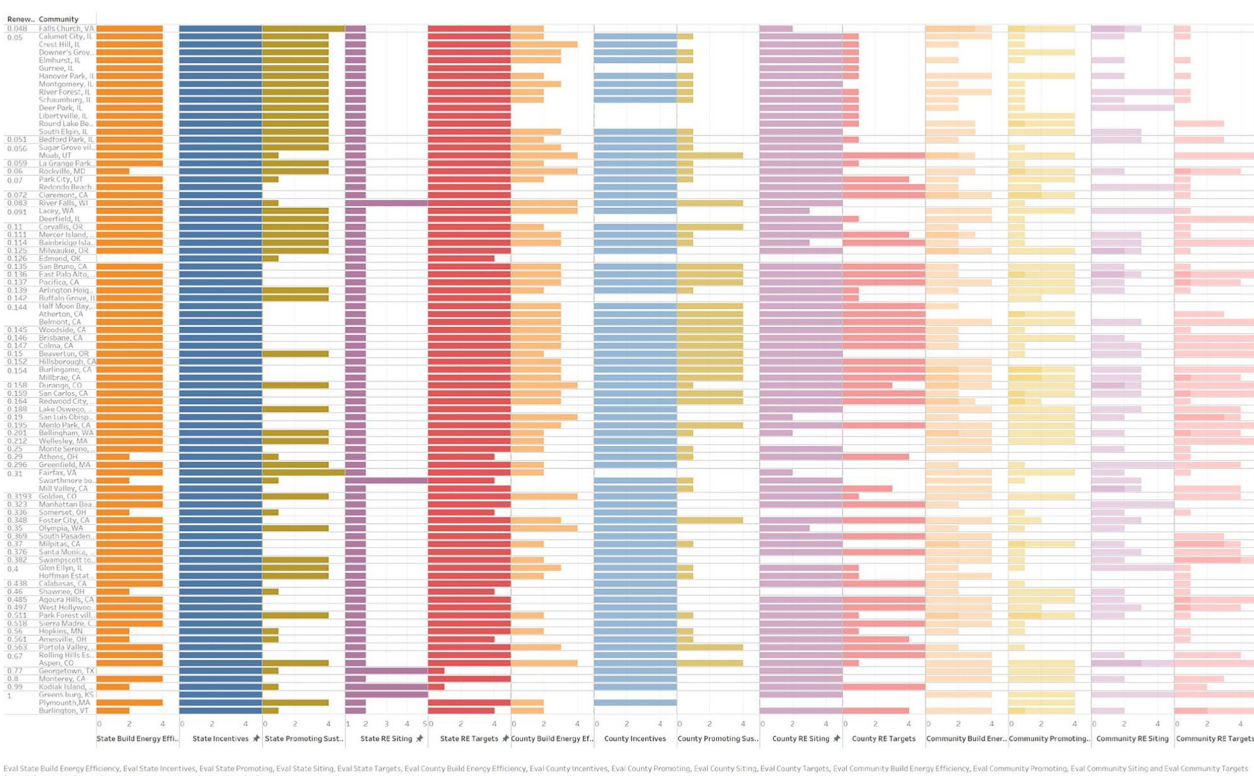

Fig. 4 Distribution of renewable energy consumption percentage in 87 communities based on local development plan indicators across multi-governance levels (data file increased the scoring data used for this study)

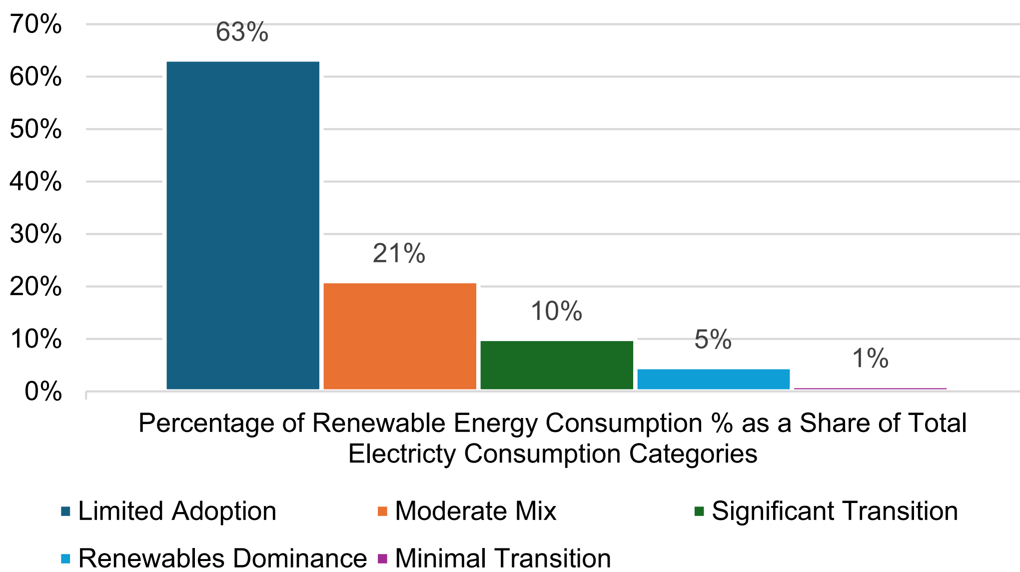

Fig. 5 Distribution of communities based on renewable energy consumption percentages

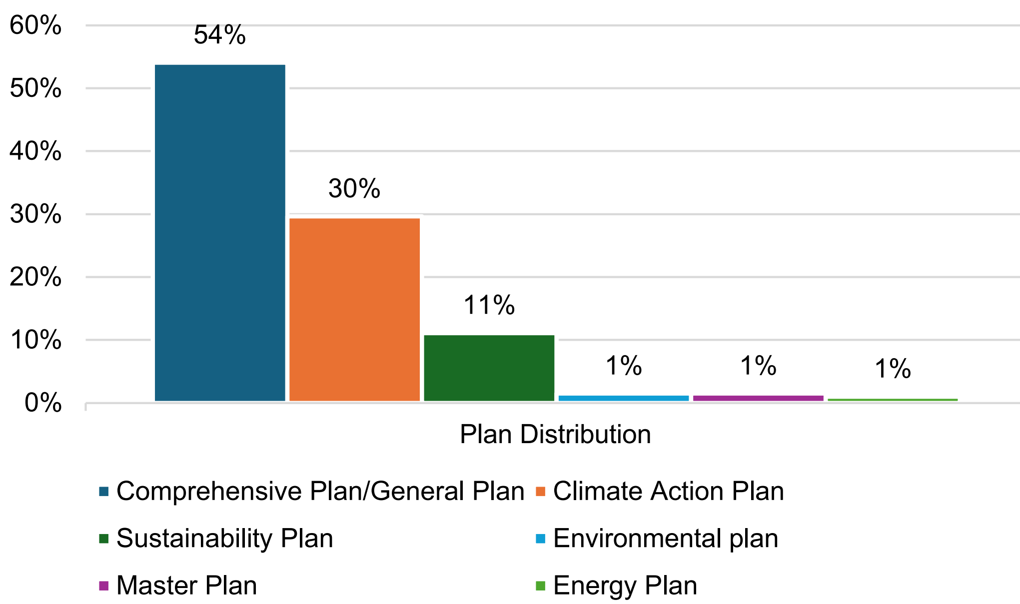

Fig. 6 Distribution of plans among the studied communities

(estimate = 0.0482 and $p = 0.025$), this suggests that establishing and supporting policies and regulations that promote building energy efficiency at the community level can significantly enhance renewable energy consumption. At the state level, renewable energy targets and goals have a significant negative impact (estimate = −0.1662, $p = 0.0002$). This indicates that while community initiatives are crucial, specific state policies may need to be reevaluated to align with renewable energy goals at the local level and can affect achieving higher renewable energy percentages.

Although county indicators have low significance for the overall renewable energy consumption percentage, promoting sustainable land use indicators (estimate = 0.0279 and a p-value of 0.0119) shows a significant negative association with the dependent variable, decreasing the percentage of renewable energy consumption. This could be due to sustainable land use policies prioritizing other land uses, such as conservation, agricultural preservation, and even large commercial and residential projects, which limit the availability of land for renewable energy projects.

Table 2 summarizes the regression analysis results of the full model, including the 14 variables excluding state incentives, where the estimate indicates the direction and magnitude of the relationship with the renewable energy percentage, the standard error measures the accuracy of the coefficient estimates, the static (*t*-value) indicates how many standard errors the coefficient is away from zero, the *p*-value assesses the significance of each coefficient, and the model fit statistics R^2 and adjusted R^2 values provide insights into how well the model explains the variability in the data. Figure 7 provides a visual representation of the regression results for model 1, showing the estimated effects of key variables across all governance levels, with error bars indicating the confidence intervals.

Table 3 summarizes the nested model, and Fig. 8 shows the result of the nested regression to identify the best-fitting model that matches this criterion. The model includes only the most significant variables, building energy efficiency at the community level, promoting sustainable land use at the county level, renewable energy targets, and promoting sustainable land use at the state level.

Content analysis

A key finding from this study is that most local governments have a lower adoption of renewable energy within their local plans than state and county governments. This implies that although higher-level governance structures are making strides toward renewable energy transition, there is a lag at the local level. For instance, Monte Sereno, CA, and Arlington Heights, IL, obtained high scores in the evaluation criteria at the state and county levels. However, their renewable energy consumption percentages are only 25% and 13.9%, respectively. This discrepancy supports the conclusion that despite supportive policies at the state and county levels, local adoption rates are lagging.

Alternatively, Aspen, CO, and Rolling Hills, CA, have achieved a renewable energy consumption percentage of 67%. In these cases, local communities, state, and county levels scored high on the evaluation criteria. This implies that alignment across all levels of governance can lead to higher renewable energy consumption. This also aligns with the findings of Attanayake et al. [102] which emphasized the importance of renewable energy adoption at the regional level to address climate change, leading to commitment and action for local governance. They discussed multiple challenges and gaps in local renewable energy adoption despite supportive policies at higher governance levels.

The successful transition to RE in communities like Georgetown, Texas, Greensburg, Kansas, and Burlington, VT, has demonstrated that local community adoption is crucial for the renewable energy transition [104]. These examples highlight the importance of integrating renewable energy into local development plans, engaging

Table 2 Model 1––regression analysis results using all predictor variables

Level	Variable	Coef. Est	Std. Error	*t* stat	*p*-value	VIF
Community	CME	0.04	0.013	3.049	0.003	1.509
	CMT	0.01	0.011	0.761	0.448	1.421
	CMS	−0.01	0.011	−1.036	0.302	1.232
	CMP	0.00	0.011	0.400	0.690	1.194
	CMI	−0.01	0.009	−0.643	0.521	1.576
County	CNE	0.01	0.018	0.567	0.572	3.884
	CNT	−0.01	0.013	−0.417	0.678	3.058
	CNS	0.00	0.015	0.085	0.932	2.179
	CNP	−0.04	0.016	−2.249	0.026	2.959
	CNI	0.01	0.012	0.697	0.487	2.401
State	STE	−0.03	0.040	−0.732	0.466	2.713
	STT	−0.16	0.043	−3.721	0.000	1.576
	STS	−0.05	0.033	−1.405	0.163	2.421
	STP	−0.03	0.015	−1.823	0.071	1.472
	Constant	1.22	0.207	5.889	0.000	n/a
Model fit statistics	R^2	0.413				
	Adjusted R^2	0.344				

Dependent variable: REC (Percentage Renewable Energy Consumption)

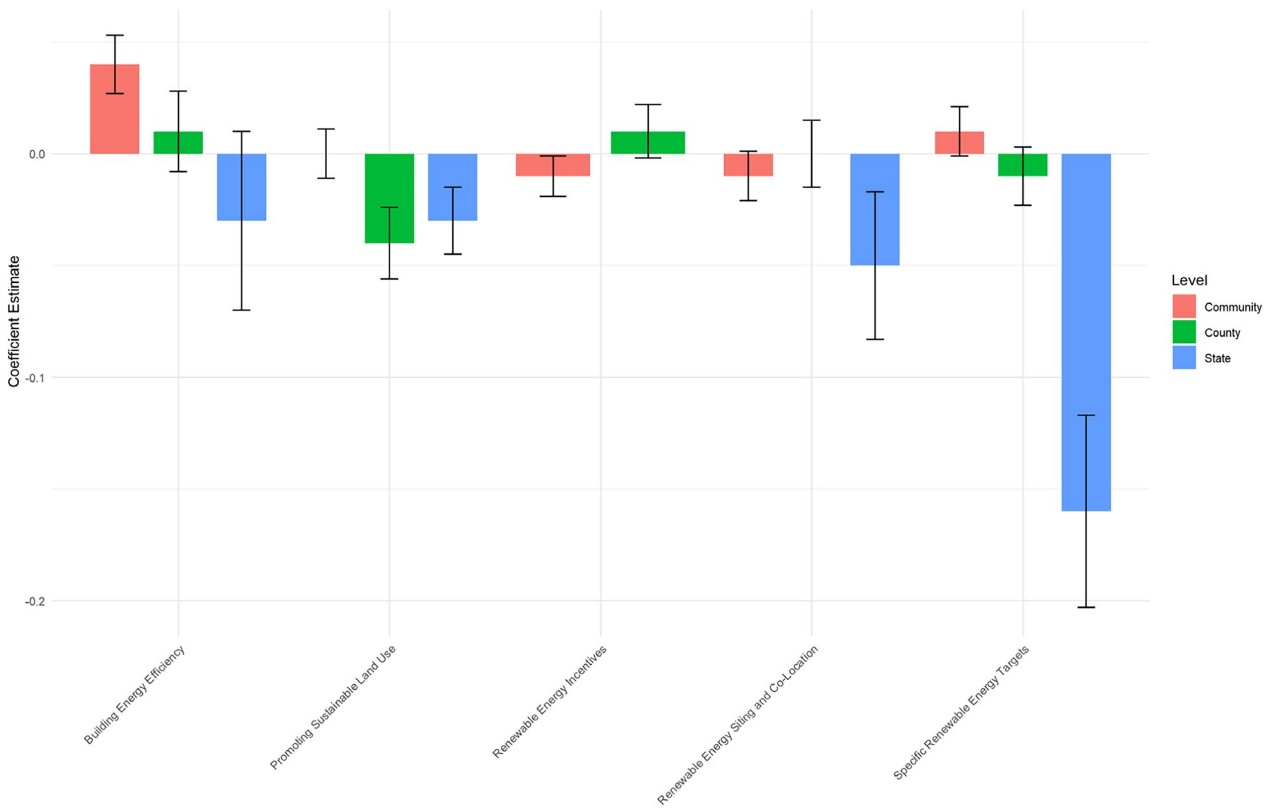

Fig. 7 Model 1––regression results for all variables across governance levels (Community, County, State Level)

Table 3 Nested model––regression analysis results using stepwise backward method

Level	Variable	Coef. Est	Std. Error	*t* stat	*p*-value	VIF
Community	CME	0.04	0.011	3.630	0.000	1.016
County	CNP	−0.03	0.011	−2.637	0.009	1.110
State	STT	−0.16	0.026	−6.114	0.000	1.208
	STP	−0.02	0.010	−2.596	0.011	1.207
	Constant	1.01	0.121	8.412	0.000	n/a
Model fit statistics	R^2	0.386				
	Adjusted R^2	0.367				

Dependent variable: REC (Percentage Renewable Energy Consumption)

the community, and developing supporting policies. For instance, Greensburg's post-tornado recovery in 2007 involved adopting LEED platinum standards for buildings, integrating renewable energy, including solar and wind, that saturated the city's energy grid, adopting sustainable development approaches such as mixed land use and preservation of farmland, as well as developing policies that allowed the houses to install small wind turbines to benefit from the available wind source [105, 106]. These were also integrated into the comprehensive plan and translated into policies that supported renewable energy siting and building efficiency. This process was characterized by significant community and local stakeholder engagement and the support of private and federal agencies through capacity development, incentives, and engagement with residents and stakeholders [107].

Discussion

At the community level, improving building energy efficiency has a positive effect on renewable energy consumption. This highlights the need for local governments to implement stringent building codes and requirements to reduce energy consumption, which in turn decreases the amount of renewable energy

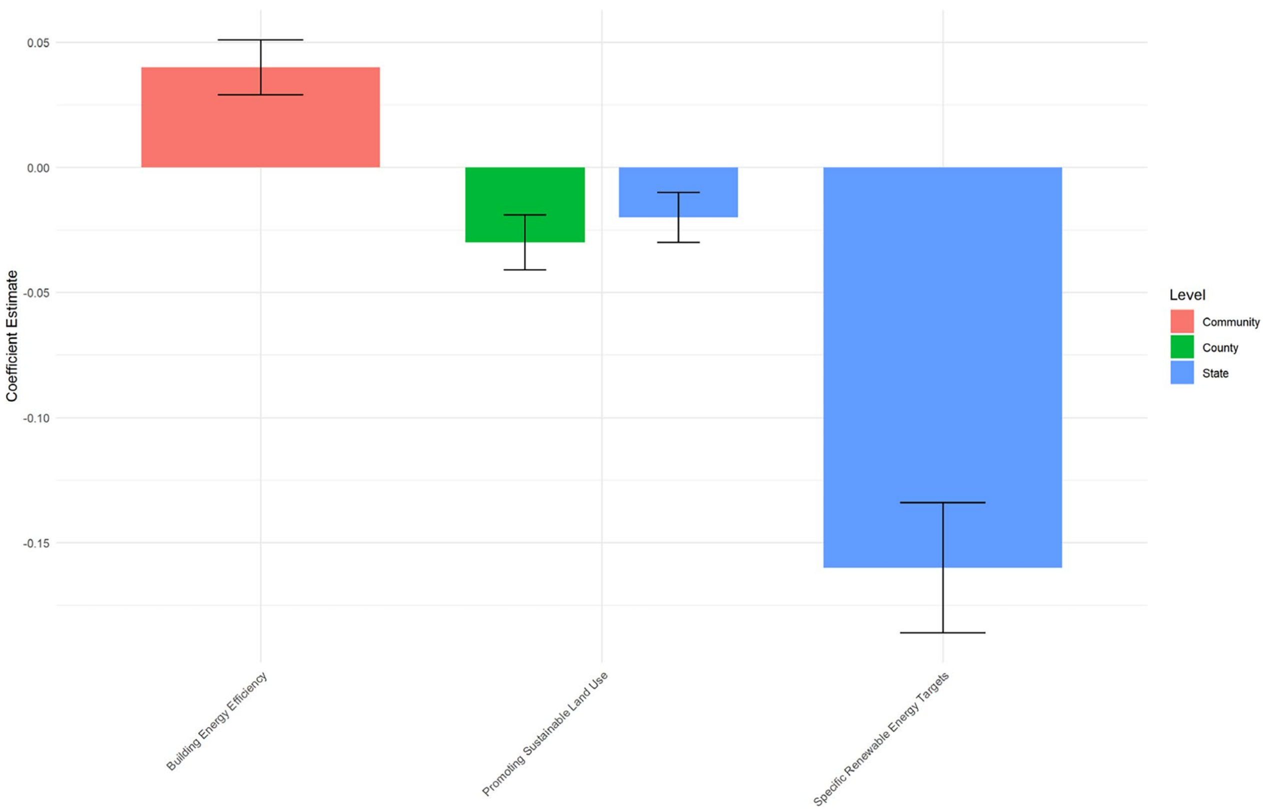

Fig. 8 Nested model––regression results by governance level (Community, County, State Level) for the most significant variables

generation needed [47]. However, setting renewable energy targets at the community level alone is not enough to drive the transition. To achieve a greater impact, states should also adopt renewable energy targets with clear plans, followed by coordination with county and local governments to establish a cohesive transition strategy.

While county-level indicators might reveal a lower significant impact on overall renewable energy consumption rates, promoting sustainable land use at the county level is still essential, especially in rural and incorporated areas where large-scale projects are frequently implemented [108]. These efforts are crucial to balancing environmental conservation with renewable energy goals. Thus, coordination between county and local levels is essential for developing land use plans that incorporate community perspectives and facilitate access to renewable energy sources while overcoming socio-economic disparities and ensuring equitable access to energy [69]. Such coordination can help achieve carbon reduction and energy needs targets more effectively [109].

At the state level, promoting sustainable land use has a negative association with renewable energy consumption percentage. The state has a role in the oversight and enforcement of land use, where state-level policies can significantly influence local actions and outcomes, as highlighted by Sullivan and Yeh [110]. In many states, the absence of state-level mandates for land use planning, combined with a strong tradition of home rule, limits the effectiveness of sustainable land use initiatives such as smart growth [111]. A comparison between Michigan and Oregon illustrates that despite the numerous initiatives in Michigan, the lack of necessary state support hinders the success of these initiatives. Whereas Oregon's model for managing urban sprawl is largely attributed to its comprehensive land use planning system, this approach demonstrates that state-level policies can guide local action effectively by establishing clear goals and guidelines that local governments must follow [111, 112]. Therefore, states should adopt sustainable land use policies to encourage local measures that reduce urban sprawl and enhance energy efficiency, suggesting that certain state policies may need reevaluation to align with renewable energy goals at the local level.

The minimal impact of renewable energy siting at all levels highlights the need for more strategic policy-focused efforts, particularly at the state level. This is largely because many of the communities in this study have not yet prioritized renewable energy as part of their ordinances and local regulations, which are often designed to address more straightforward development projects [113, 114]. This silence can act as a barrier to renewable energy deployment with a lack of proactive measures to incorporate renewable energy considerations into local planning [115]. The study also found that communities that included renewable energy siting and rooftop solar in their plans, often aligned with states that have supporting frameworks. This is evident in places like Greensburg, KS, Aspen, CO, Manhattan Beach, CA, Glen Ellyn, IL, and Bainbridge Island, WA. This alignment allows for a balance between state and local control, enabling local authorities to have meaningful input into renewable energy projects while reducing challenges to developers by streamlining processes and setting clear standards [116].

The reviewed comprehensive plans showed exclusion of energy planning in their local planning; thus, engagement does not capture communities' preferences on energy sources, energy zoning, locations, and energy efficiency. And current public consultation for renewable energy development remains within the "decide-announce-defend" (DAD) model, that cannot be characterized as community engagement practice that empowers community [117]. The implementation of stringent building codes, renewable energy targets, and renewable energy zoning requires active engagement with local stakeholders. While state growth management law requires allowing the public to participate in local planning process [118], critical questions remain about who participates and how participation affects outcomes [115, 119].

Early public engagement through clear guidelines––beyond tokenistic hearings [122]––can help identify suitable locations for renewable infrastructure, minimizing land use conflicts, and increase energy efficiency. This pre-consultation approach can potentially decrease opposition and attract investment by reducing regulatory uncertainty [123], not only at a project level but also a whole transition approach.

Conclusions

This study contributes to the scientific understanding of energy transition and multi-level governance by providing valuable insights into the factors influencing renewable energy transition at the local level and the roles of states and counties. However, it is still limited in several ways. Community identification relies on multiple sources, including EPA, Sierra Club, Web search, and NREL, and may not include all communities that have started their renewable energy transition. In addition, data availability is another barrier that affects research quality, where significant information is not published. Therefore, accuracy of the findings depends on the quality and availability of the data used. At the same time, the analysis can benefit from the community's experiences in future to develop lessons learned. This study was based on a scoring criterion depending on the identified and defined themes in the research, meaning that the search methodology affects the themes identified, and this comes with a restriction in subjectivity in the developed scores. Finally, this study provides a snapshot of the situation at a specific time, and changes in policies, technologies, or other factors can alter these relationships over time. Future research can address these limitations, explore the driving factors, and determine whether the impacts of initiation at different levels influence the transition pathway.

A multi-level governance approach to transitioning to renewable energy at the local level is crucial to ensure communities with different contexts can adopt renewable technologies. The findings reveal that while state and county policies provide a supportive framework, successful implementation depends on local efforts. Therefore, local governments should engage communities early in the planning process to increase their engagement and facilitate the implementation of renewable energy projects. Additionally, the importance of local involvement in achieving renewable energy targets recommends that future policy development should establish a clear pathway for local governments to follow, rather than relying on broad ambitions without clear implementation strategies. Besides, long-term development plans, such as comprehensive plans, can integrate spatial and techno-economic analysis findings into land use and zoning reforms. This approach can provide a clear understanding of the potential for renewable energy across municipality's district and opens the possibility of energy sharing among neighboring communities.

Renewable energy planning also requires designing secure, reliable, and cost-efficient systems as well as taking into consideration resource availability, geography, technology, consumer demand, energy variability, environmental impact, and infrastructure. Therefore, careful evaluation of challenges and trade-offs is necessary to ensure successful planning and local acceptance for successful transitions. These insights are valuable for policymakers seeking to enhance renewable energy transition and achieve sustainable energy goals. Moreover, this finding elaborates on the importance of state-level policies in shaping local policies and actions. Their broad perspective on regional energy planning can support local communities by offering additional resources to address energy shortages and developing energy trading frameworks that balance land conservation with renewable energy goals. State governments can also leverage federal funding and offer additional incentives to facilitate project development and turn local plans into action.

In conclusion, this study provides a foundation for future research into the effectiveness of different governance levels in promoting renewable energy adoption and energy efficiency. The significant impact of community-level and county-level factors highlights the need for integrated policy approaches that involve local communities and counties in developing siting policies, assessing local land potential, and developing land use, implementing energy-efficient land development measures and building energy efficiency to achieve set targets.

A limitation of this study is the neutrality of our hypotheses regarding the direction of the effects of governance policies on renewable energy consumption. This approach was intentional, as prior research has not consistently established whether certain policies lead to increased or decreased renewable energy adoption. For example, while building energy efficiency policies are generally expected to have a positive effect, state-level renewable energy targets in our study showed a negative association. This suggests that implementation dynamics, policy interactions, and enforcement mechanisms play a critical role in determining outcomes. Future research could further explore these complexities, including case studies of how specific policy designs contribute to positive or negative outcomes in different governance contexts.

Future research could improve our understanding of barriers to local renewable energy adoption and the specific challenges local communities face in adopting such initiatives. There is also a need to better understand the impact of policy changes and regulations on the federal, state, and local levels as changes continually evolve. Research should also explore the relationship between socio-economic factors and demographic characteristics of communities on energy transitions. Additionally, future studies should assess how various governance structures, policies, and regulations influence annual renewable energy generation rates and the success of renewable energy initiatives by tracking the effects of policy changes over time. Effective community engagement is critical to the success of renewable energy projects, and future research could evaluate different engagement strategies and the economic impacts associated with locally transitioning to renewable energy to address community concerns. Finally, integrating renewable energy planning with other urban and rural development goals can help create holistic and sustainable community development plans.

Supplementary Information

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Supplementary material 1.

Supplementary material 2.

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H.W. conducted data collection, data cleaning, comprehensive review, and data analysis and wrote the main manuscript. N.K. reviewed the data analysis, developed tables 1, 2, 3 and reviewed the manuscript.

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Declarations

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