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Research article

A spotlight on fossil fuel lobby and energy transition possibilities in emerging oil-producing economies

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ABSTRACT

This study investigates the impact of fossil fuel industry on renewable energy deployment in emerging oil-producing economies, using Ghana as the subject of analysis. Drawing on the "theory of lobby," the study extends previous analyses to examine how fossil fuel production influences the possibility of transitioning to renewable energy. The results, based on a stepwise estimation technique, within a two-regime Markov-switching Model, show a consistent negative relationship between fossil fuel production and renewable energy deployment, supporting the lobby effect theory in Ghana's energy economy. Notably, while fossil fuel production initially increases the probability of transitioning to renewable energy (from 39.65 % to 58.42 %), this trend is reversed by foreign direct investment, reducing the likelihood to approximately 42 %. These findings underscore the need to expand the lobby-effect theory to include indirect economic influences, such as investment patterns and structural dependencies, that enable fossil fuel dominance. Through its focus on Ghana, this study contributes fresh insights into the energy transition dynamics of emerging economies, offering a broader and more inclusive perspective to the energy transition literature.

1. Introduction

The global shift toward more sustainable energy sources is a topic of rich discussion, with clear support and subtle resistance [1]. A major source of this resistance comes from the lobbying efforts of established fossil fuel industries, often aimed at blocking policies for climate change mitigation and the adoption of cleaner energy alternatives [2]. While such opposition is highly observed in advanced economies like the United States, it seems to be less pronounced, or even absent in other regions [3]. The prevailing perception is that lobbying by the fossil fuel sector has a minimal impact on the transition towards renewable energy in developing economies, possibly due to limited media attention [4]. However, this view has been increasingly contested. Scholars argue that even in the absence of visible lobbying, many emerging economies exhibit a slow shift from fossil fuels to renewable energy, suggesting that the influence of

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fossil fuel interests, whether direct or indirect, cannot be discounted [5]. These observations raise critical questions central to understanding energy transitions: Is there a less recognized, silent opposition to climate change mitigation and the broader agenda of transitioning to cleaner energy systems? More specifically, how does fossil fuel production in oil-producing economy affect renewable energy deployment and the possibility of transitioning to a cleaner energy state?

Ghana provides an intriguing case for exploring these questions, given its evolving energy sector and reliance on fossil fuels. Despite structural shifts, such as a transition from hydro-based energy to a hydro-thermal mix and increasing private sector involvement, Ghana's energy landscape remains heavily dependent on fossil fuels [6]. As illustrated in Fig. 1, the growth rate of nonrenewable energy sources, particularly between 2014 and 2017, consistently outpaced that of renewables [7].

This persistent reliance on fossil fuels in Ghana, despite the absence of visible lobbying efforts akin to those in advanced economies, highlights the need for a deeper investigation into the factors shaping its energy transition. Unpacking these dynamics is crucial for understanding the barriers to renewable energy adoption and for informing policy interventions aimed at achieving sustainable energy goals.

Despite the indicated relevance, only a limited number of studies on energy transition have focused on the implied effect of the fossil fuel industry [2]. This notable research gap is particularly evident in the context of how the industry impacts the shift towards renewable energy sources. The majority of existing research concentrates on advanced economies and predominantly employs qualitative methods, which, while insightful, lacks the robust empirical estimation needed to fully comprehend the industry's impact [2,3]. Studies focusing on Ghana's energy transition, such as those by Osei-Tutu et al. [6], Kuamoah [8], and Siakwah et al. [9], have highlighted the shift in energy mixes and policy targets but limited in addressing the specific role of the fossil fuel industry. These studies are often limited by their narrow focus on structural energy changes and policy discussions, neglecting the dynamic interactions between fossil fuel production and renewable energy deployment. Additionally, these papers rarely explore the broader economic factors and external pressures, such as the influence of fossil fuel interests, as the "Lobby-Effect Theory" suggests. Again, the few studies that do incorporate empirical methods often fall short in rigor, as they do not adequately account for the dynamic patterns of economic variables and the underlying processes driving these patterns, leading to a potential underestimation. For instance, while Asante et al. [10] and Agyekum & Nutakor [11] provide valuable insights into the adoption of renewable energy in Ghana, they do not empirically explore the implications of the fossil fuel industry's influence on the energy transition. Furthermore, there appears to be an absence of comprehensive studies examining the fossil fuel industry's activities and their effect on the prospects of energy transition, especially in emerging economies like Ghana [2].

Building on these issues, this study provides a framework for understanding how the fossil fuel industry influences the deployment of renewable energy in developing countries. In particular, the study seeks to achieve the following specific objectives, using Ghana as the subject of analysis. First, test for the "Lobby Effect Theory" by estimating the relationship between fossil fuel production and renewable energy growth. Second, estimate the associated effect on the possibility of transitioning to a renewable energy state. Third, provide an explanatory summary of the estimates, including a discussion on the broader implications of the results for emerging economies.

Due to constraints imposed by the unavailability of comprehensive data across the entire energy landscape, the analysis is limited to the electricity sector, allowing for detailed and accurate assessment of trends in the growth of nonrenewable (fossil fuel) and renewable sources [12]. The electricity sector serves as a critical indicator of overall energy transition trends and is often at the forefront of shifts towards more sustainable energy practices [12]. As such, it provides a valuable lens to examine the broader implications of energy production choices and the potential influence of fossil fuel interests even in the absence of overt lobbying activities.

This study makes novel contributions to the energy transition literature by addressing key gaps and extending existing frameworks in meaningful ways. First, it enhances the analytical framework by employing a Markov-Switching Model to explore the nuanced impact of fossil fuels on energy transition prospects, building on the foundational "Lobby Effect Theory" discussed in earlier works such as Aguirre and Ibikunle [13]. This approach goes beyond previous analyses by capturing regime-dependent dynamics and transition probabilities, offering deeper insights into energy transition pathways. Second, the study diverges from the predominantly qualitative

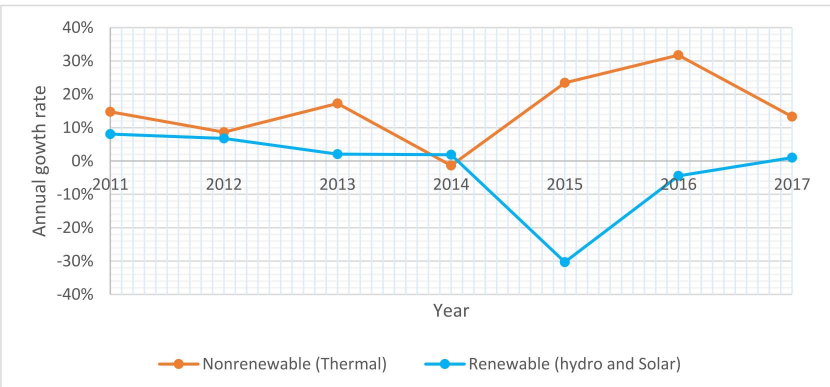

Fig. 1. Electricity generation since 2011 (Annual growth rate).
Source: Ankrah and Lin [7].

methodologies in the literature, instead providing a rigorous empirical approach that delivers robust estimates of the impact of fossil fuel production while accounting for the dynamic interplay of economic variables—an aspect often neglected in prior research. Finally, by focusing on Ghana, this study introduces a unique perspective, highlighting the challenges and opportunities of energy transitions in an emerging oil-producing economy. Unlike previous research, which primarily centers on advanced economies, this work expands the geographical scope of energy transition discourse, offering a more global and inclusive understanding of these dynamics. Additionally, while the authors have explored related topics in earlier works, this study is distinct in its methodological rigor and its application to a context largely underrepresented in the literature, making a significant and original contribution to the field.

The remaining sections of this study are structured as follows: Section 2 profiles an analytical review of the existing literature, particularly in light of how the fossil fuel industry influence cleaner energy deployment. Section 3 presents the methodology, while sections 4 and 5 show the results and discussion, respectively. The policy implication and conclusion of the study are presented in sections 6 and 7, respectively.

2. Analytical review of the fossil fuel Industry's opposition

This section profiles a brief background of the opposition from the fossil fuel industry, particularly its resistance to climate change mitigation and the energy transition agenda. This is squarely linked to review of closely related studies and is analytically presented to serve as a complement to the introduction, expanding the understanding of the study.

2.1. Background and review of related studies

Governmental initiatives aimed at reducing the impacts of climate change continue to meet significant resistance, particularly from sectors with high energy demands and established fossil fuel industries. These groups often fear that climate mitigation policies might hinder their growth and profitability [14]. A prime example of this resistance is seen in the denialist conservative movement in the United States [15]. These interest groups adopt various strategies to oppose climate legislation, one of which includes direct interactions with politicians [16]. Lobbying firms, representing these interests, allocate vast sums of money to political groups to subtly stall, obstruct, or weaken climate mitigation and related energy transition policies. For instance, in 2020 alone, Shell contributed over $10 million to help block climate action [17].

While some literature suggests that this phenomenon is mainly prevalent in the United States and less visible elsewhere [18], other scholars like Kukkonen et al. [3] argued that despite the low visibility, many countries still lack effective climate change policies which might be due to extensive lobbying efforts from the fossil fuel industry. Recognizing this puzzle, Vesa et al. [2] sought to investigate "whether there is a quiet opposition operating outside the media spotlight" in Finland. They found that an alliance favoring economic interests over climate improvement exerts significant influence on policy decisions through direct lobbying, highlighting the power of economic lobbies in shaping climate policy, beyond media strategies.

Beyond direct political opposition, the fossil fuel industry strategically employs financial markets, trade networks, and technological influence to protect its dominance, creating significant barriers to renewable energy adoption. For instance, Irfan et al. [19] identified financial development as a crucial driver of renewable energy investments but emphasized that dependence on mineral markets hinders energy transitions. Similarly, Gyamfi et al. [20] demonstrated that while robust financial systems in G-7 and E−7 economies facilitate renewable energy projects, entrenched fossil fuel market interests actively resist these transitions to safeguard profitability. Though these findings highlight the dual-edged nature of financial systems in supporting or obstructing sustainable energy shifts, more recent studies emphasize the importance of integrated financial and regulatory systems in overcoming resistance from entrenched fossil fuel interests. In this category, Tsai [21] illustrated how green finance tools can unlock renewable energy potential and facilitate climate goals, aligning with policy strategies aimed at mitigating fossil fuel dominance. Cheng and Jiang [22] highlighted the role of market dynamics by showing how interactions between carbon markets, green bonds, and clean energy can impact renewable energy adoption, especially during periods of volatility. Moreover, the issue of greenwashing, as discussed by Li et al. [23] adds another layer of complexity. Their study shows how deceptive practices by corporations can mislead stakeholders, creating additional challenges for renewable energy transitions. These dynamics underline the need for transparency and stronger regulatory oversight, as the economic power of fossil fuel interests can indirectly hinder clean energy adoption.

In addition to financial mechanisms, the interconnectedness between fossil energy and other sectors offers critical insights into energy transition dynamics. For example, Wu et al. [24] examined the volatility spillovers between fossil energy and agricultural commodities, finding that external shocks like the COVID-19 pandemic and the Russia-Ukraine conflict intensified market instability, with the latter having a more immediate and pronounced impact. These disruptions demonstrate how external shocks in one sector can propagate resistance to climate mitigation efforts in others. Moreover, Husin et al. [25] explored the integration of Blockchain-BIM technology within Indonesia's renewable energy framework, highlighting how such advancements can address cost-performance challenges in compliance with green regulations, offering lessons for countries grappling with similar constraints.

Technological progress, while often seen as a facilitator of the energy transition, can also pose challenges. For instance, Li et al. [26] found that in China, technological advancements intended to enhance renewable energy adoption are sometimes co-opted by fossil fuel industries to delay transitions. Similarly, Zhang et al. [27] analyzed the dual role of green finance and high-tech innovation in the Yangtze River Economic Belt, showing that while these innovations align with climate goals, the influence of fossil fuel entities can dilute their impact. On a more granular level, Kurniawan et al. [28] emphasized the importance of energy-efficient technologies in sustainable building design, demonstrating how advanced tools can optimize energy consumption and reduce environmental footprints. Together, these studies reveal the complex interplay between technological progress and fossil fuel interests, highlighting the need for balanced approaches that leverage innovation while addressing industry resistance.

The role of international trade in shaping energy transition trajectories has also been documented. Wu et al. [29] demonstrated that trade intensity with China increases carbon emissions in Belt and Road countries, as economic ties with fossil fuel-dependent economies impede the adoption of renewable energy technologies. This dynamic is particularly relevant in developing nations like Ghana, where trade relationships with fossil fuel exporters can reinforce structural barriers to energy transition efforts. Together, these studies reveal a multifaceted resistance posed by fossil fuel interests across financial, technological, and trade domains, underscoring the complexity of achieving sustainable energy transitions.

It is worth stating that other analyses have been conducted in the broader discourse on energy transition. In particular, Megura and Gunderson [30] employed qualitative and critical discourse methods to delve into the dual pressures of environmental responsibility and business imperatives on fossil fuel companies. Wright et al. [31] analyzed media narratives and industry public relations to uncover how fossil energy maintains its stronghold in Australia, a country grappling with the climate crisis. York and Bell [32] disputed the notion of a renewable energy transition, arguing that new energy sources have historically supplemented, not supplanted, fossil fuels, cautioning that mislabeling this growth as a transition could impede effective climate policy. Noting the industry's efforts to preserve its established position, Szabo [33] investigated the EU natural gas industry's strategic adaptation to climate policies. The author found that as the EU enhanced climate targets, the natural gas industry incumbents were forced to adapt the fuel's discourse according to the changing context. Hielscher [34] examined the socio-political push and pull in Europe's move away from fossil fuels, pointing out that political and industrial actions can stall the shift towards cleaner energy. Hansen [35] quantified the economic impact of climate stabilization on the fossil fuel industry, advocating for a strategic reduction in fossil fuel demand to overcome resistance from the industry. Bricout [36] also explored the changing geopolitical influence of European IOCs within the energy transition, suggesting a diminishing role due to the emergence of national oil companies and a global reduction in oil activities. Thus, these studies provide a multifaceted view of the challenges and strategies within the ongoing global discourse on energy transition.

Ghana provides a compelling case study in the broader discussion of energy transition challenges, particularly in developing and oil-producing nations. Despite the structural shifts in its energy sector, progress toward a greener energy future has been limited. For example, Osei-Tutu et al. [37] investigated whether Ghana has undergone an energy transition, focusing on its electrical energy sector. The study highlights key structural changes, such as a shift from a hydro-based energy mix to a hydro-thermal mix, and from a state-controlled to a state-private energy supply. However, the study concludes that a sustainable transition to greener energy has not yet occurred, with renewable energy making up less than 1 % of the electrical mix. Similarly, Kuamoah [38] critically reviews Ghana's renewable energy potential, showing that despite significant opportunities, renewable energy remains underutilized. The gap between policy goals and actual implementation is evident, as renewable energy still plays a minimal role in the country's energy mix. On a smaller scale, the transition to renewable energy in Ghana is also being examined at the level of small and medium enterprises (SMEs). Asante et al. [39] analyze the adoption of solar energy among SMEs, emphasizing the influence of pro-environmental norms and social pressures in driving this adoption. Their findings suggest that while solar energy adoption is growing, broader economic and social factors limit its full potential. Economic and technical factors further complicate Ghana's energy transition. Agyekum and Nutakor [40] assess the feasibility of hybrid renewable energy systems in Southern Ghana, demonstrating that while such systems are technically viable, economic challenges—particularly related to investment climate—continue to hinder their development. The challenges Ghana faces are not unique. Siakwah et al. [41] provide a comparative analysis of energy transitions in Russia and Ghana, highlighting similar structural barriers in both countries, such as resource limitations and dependence on hydrocarbon-based systems. This comparison underscores the broader issues developing nations encounter in balancing economic growth with energy sustainability. The complexity of achieving an energy transition in oil-producing countries like Ghana is further explored by Ankrah et al. [12]. Their study examines whether energy transitions are feasible in such contexts, focusing on the challenges posed by dependence on oil revenues. The study reveals significant economic and policy challenges in balancing oil production with the transition to renewable energy, reflecting the broader struggle between fossil fuel interests and the global push for a greener future.

For clarity and ease of understanding, Table 1 provides a summary of the key findings and methodologies of these related studies, drawing connections to the variables in the present study. This is to provide a clearer overview of the research landscape and lay the groundwork for the discussion on the theoretical and methodological considerations, including the justification of the variables selected for examination in this study.

2.2. *Theoretical framework and methodological considerations*

The existing literature is underpinned by a variety of theories that provide insights into the energy transition, especially in light of the connection between fossil fuels to renewable energy. The Lobby Effect Theory is particularly prominent, emphasizing how fossil fuel industries actively influence policy-making to protect their market dominance and profitability, often at the expense of renewable energy development. Studies by Dunlap and McCright [14] and Brulle [16] document the organized resistance of fossil fuel entities, revealing their strategic lobbying and financial interventions to obstruct climate mitigation efforts. Complementing this is the Resource Curse Theory, which explores how dependence on fossil fuel revenues creates structural challenges that hinder economic diversification and renewable energy adoption. Another relevant framework is the Multi-Level Perspective (MLP), employed by Siakwah et al. [41], which examines the interplay between socio-technical systems, institutions, and policies to understand energy transition dynamics. Together, these theories underscore the complex socio-political and economic barriers to achieving sustainable energy transitions, particularly in developing economies.

Building on these theoretical foundations, the methodological approaches in the literature are diverse and tailored to the specific aspects of energy transitions under investigation. Quantitative methods dominate the field, with econometric techniques such as the

Table 1
Summary of relevant literature and their significance to this study.

Study	Methodology/Approach	Key Findings	Variable(s) considered	Relevance to Current Study
Dunlap & McCright [14]	Qualitative analysis of climate denialism	Highlights the organized efforts of the climate denial countermovement, including lobbying and misinformation.	Fossil fuel lobbying, political opposition	Demonstrates how lobbying efforts obstruct climate policies, relevant for understanding the resistance to renewable energy transition.
Boussalis & Coan [15]	Text-mining and content analysis	Identifies patterns of doubt in climate change communications and strategies used to challenge climate science.	Climate change doubt, communication strategies	Provides insights into how subtle opposition can undermine renewable energy transitions, relevant for understanding indirect resistance in Ghana.
Brulle [16]	Structural analysis of U.S. countercoalitions	Examines the network structure of climate change countercoalitions and their strategies to block climate action.	Political networks, lobbying strategies	Highlights the role of coordinated opposition in delaying energy transitions, offering parallels for indirect lobbying influences in Ghana.
Rhomberg [18]	Qualitative analysis of climate communication in Austria	Explores how climate change communication shapes public perceptions and influences policy engagement.	Climate communication, public perception	Demonstrates the role of communication in fostering or hindering climate policies, relevant for understanding how public narratives affect renewable energy transitions.
Vesa et al. [2]	Survey of policy networks, comparative analysis	Economic interests lobby against climate mitigation in Finland.	Fossil fuel lobbying, political influence	Shows how lobbying can influence energy policies even with limited media attention.
Kukkonen et al. [3]	Comparative analysis, media data	Fossil fuel lobbying has hidden influence on climate policies.	Fossil fuel lobbying, media presence	Highlights the subtle but powerful impact of fossil fuel lobbying, applicable to developing economies like Ghana.
Irfan et al. [19]	Panel data analysis using the CS-ARDL model	Financial development and environmental regulations positively influence renewable energy transition in the long run. However, reliance on mineral markets hinders this transition.	Financial development, environmental regulations, mineral markets	Emphasizes the dual role of financial systems in facilitating or obstructing renewable energy deployment.
Gyamfi et al. [20]	Panel data analysis (G-7 and E−7 countries)	Financial development can support renewable energy, but fossil fuel markets resist.	Financial development, fossil fuel dependency	Shows the potential impact of financial systems and fossil fuel dependency on renewable energy transition.
Tsai [21]	Case study analysis	Green finance tools, such as subsidies and policies, significantly promote renewable energy development and greenhouse gas reduction.	Green finance, renewable energy development	Demonstrates the role of financial instruments in overcoming fossil fuel dominance
Cheng and Jiang [22]	Empirical analysis using DCC-GARCH and TVP-VAR-SV models	Carbon markets positively influence renewable energy in the short and medium term but face volatility risks from external shocks.	Carbon markets, renewable energy	Demonstrates how market mechanisms like carbon markets can drive renewable energy adoption, offering insights into Ghana's energy policy structure.
Li et al. [23]	Empirical study on corporate practices	Greenwashing boosts short-term stock performance but negatively impacts long-term investments, misleading stakeholders.	Greenwashing, investor behavior	Highlights the risks of misinformation in renewable energy markets, underlining the importance of transparency in fostering sustainable investment.
Wu et al. [24]	Time-frequency volatility analysis of fossil energy and agricultural commodities	Fossil energy volatility spillovers intensify during crises, with stronger impacts observed during the Russia-Ukraine conflict compared to COVID-19.	Fossil energy volatility, agricultural commodities	Demonstrates the interconnectedness of energy markets, emphasizing how external shocks influence renewable energy transitions in interdependent economies.
Husin et al. [25]	Integration of Blockchain-BIM technology	Blockchain-BIM enhances cost-efficiency and regulatory compliance in renewable energy systems.	Blockchain-BIM, renewable energy cost-efficiency	Highlights the role of innovative technologies in addressing renewable energy challenges, offering lessons for cost-effective energy transitions.
Li et al. [26]	Empirical analysis of technological advancements	Technological advancements significantly contribute to sustainable development but with regional disparities influencing the effectiveness of these technologies.	Technological progress, fossil fuel influence	Warns of the potential for technological innovations to be undermined by fossil fuel interests.

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Table 1 (*continued*)

Study	Methodology/Approach	Key Findings	Variable(s) considered	Relevance to Current Study
Zhang et al. [27]	Empirical analysis-Sustainable development index	Green finance and high-tech innovation support sustainable development. However, the impact varies across different regions within the economic belt.	Financial development, green finance	Highlights the challenges in implementing green initiatives due to fossil fuel industry resistance
Kurniawan et al. [28]	Energy analysis and efficiency assessment of sustainable building designs in Indonesia.	Implementing energy-efficient technologies in building designs leads to significant reductions in energy consumption and environmental impact	Energy efficiency, sustainable building design	Demonstrates the role of energy-efficient technologies in reducing reliance on fossil fuels
Wu et al. [29]	Panel data analysis of trade intensity and emissions	Trade intensity increases carbon emissions, impeding renewable energy adoption	Trade openness, carbon emissions	Relevant for understanding how international trade relationships can influence energy transition efforts
Megura and Gunderson [30]	Qualitative and critical discourse analysis	Fossil fuel companies face tension between environmental responsibility and business imperatives.	Corporate influence, environmental responsibility	Provides insights into how fossil fuel industries balance business and environmental concerns, informing policy approaches.
Wright et al. [31]	Media and public relations analysis	Fossil energy maintains dominance in Australia despite climate crisis awareness.	Media influence, fossil fuel dominance	Highlights how fossil fuel industries can maintain dominance through media, relevant to Ghana's developing media landscape.
York and Bell [32]	Historical energy analysis	New energy sources often supplement rather than replace fossil fuels.	Energy transition, renewable energy	Provides a cautionary perspective on energy transitions, indicating that new energy sources may not immediately replace fossil fuels.
Szabo [33]	Discourse analysis	EU natural gas industry adapts to climate policies while maintaining fossil fuel reliance.	Fossil fuel dependency, energy policy	Relevant to understanding how fossil fuel industries adapt and influence energy policies, applicable to Ghana's context.
Hielscher [34]	Socio-political case analysis	Political and industrial actions can stall shifts towards cleaner energy.	Energy policy, socio-political factors	Emphasizes the role of political and industrial factors in slowing energy transitions, relevant to developing economies.
Hansen [35]	Stranded asset analysis	Fossil fuel stabilization requires demand reduction to overcome industry resistance.	Fossil fuel demand, economic impact	Provides economic insights on reducing fossil fuel demand, critical for understanding Ghana's energy transition.
Bricout (2022)	Geopolitical analysis of European IOCs	European IOCs are losing geopolitical influence as the world transitions away from oil.	Geopolitical influence, fossil fuel markets	Highlights the geopolitical impact of the energy transition, providing insights for Ghana as an oil-producing nation.
Osei-Tutu et al. [37]	Thematic content analysis	Ghana's electrical energy sector has transitioned from exclusively hydro-based to a hydro-thermal mix, with thermal energy constituting about 69 % of the 2020 generation mix.	Energy source type, energy ownership and management, renewable energy policy targets	Underscores the challenges in achieving a sustainable energy transition, relevant to discussions on the interplay between fossil fuel reliance and renewable energy deployment.
Kuamoah [38]	Comprehensive review and critical evaluation	Ghana faces challenges meeting SDG 7 targets due to reliance on non-renewable energy sources despite significant renewable energy potential.	Energy consumption trends, renewable energy policies	Highlights the gap between renewable energy potential and actual deployment in Ghana, emphasizing the importance of policy interventions for cleaner energy transitions.
Asante et al. [39]	Cross-sectional survey using structural equation modeling	Pro-environmental norms showed the strongest association with solar energy adoption. Integrating constructs from innovation-diffusion and environmental psychology models enhances insights.	Relative advantage, observability, personal norms, social norms, policy incentives	Offers insights into addressing the social and psychological barriers in energy transition.
Agyekum and Nutakor [40]	Techno-economic evaluation using LCOE and NPC metrics	The PV-Wind-DG-Battery system and the Wind-DG-Battery system recorded higher LCOEs than current energy costs but could be viable under favorable investment climates.	LCOE, NPC, fuel cost, discount rates, inflation rates	Highlights the economic challenges of renewable energy projects in Ghana and the need for policy interventions to create a favorable investment climate, relevant to fostering energy transitions.
Siakwah et al. [41]	Case study combining a critical literature review and primary	Energy transition in Ghana is slow due to resource constraints, limited	Transition framing (landscape, regime,	Highlights the complexity of energy transitions in developing countries

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Table 1 (*continued*)

Study	Methodology/Approach	Key Findings	Variable(s) considered	Relevance to Current Study
	data through interviews, analyzed using the Multi-Level Perspective (MLP) framework.	incentives, and reliance on hydrocarbon systems, while Russia's transition is shaped by centralized energy policies and institutional rules.	niche), socio-technical systems, social justice	like Ghana, emphasizing that context-specific challenges require tailored approaches beyond universal frameworks.
Ankrah et al. [12]	Two-state Markov Switching Model (MSM) applied to multivariate state-dependent regression using data from 1980 to 2019.	Fossil fuel production hinders renewable energy, while trade openness and foreign direct investment (FDI) promote cleaner energy growth.	Fossil fuel production, renewable energy, trade openness, foreign direct investment (FDI)	Provides quantitative evidence on Ghana's transition probabilities and the effects of fossil fuel production and economic variables on renewable energy growth, directly aligning with energy transition themes.

CS-ARDL model and panel data analysis frequently employed to assess the effects of fossil fuel dependency and other relevant variables on renewable energy deployment. For instance, Irfan et al. [19] and Gyamfi et al. [20] utilize these advanced statistical models to quantify the long-term and short-term drivers of energy transitions in both developed and developing economies. On the other hand, qualitative methods provide deeper contextual understanding, as seen in Siakwah et al. [41] and Megura and Gunderson [30], which use critical discourse analysis and the MLP framework to explore socio-technical and policy barriers in energy transitions. Additionally, mixed-method approaches, like those integrating case studies and primary data collection through interviews, offer a comprehensive perspective by combining quantitative rigor with qualitative depth.

2.3. *The lobby-effect theory and variables of study*

As we have already stated, the Lobby-Effect Theory stands out for its direct relevance to this study. In the fossil fuel industry, the lobby-effect theory posits that powerful interest groups, such as major oil companies and their associations, wield substantial influence over government policies and regulations through extensive lobbying efforts [12]. These efforts often focus on shaping legislation and regulatory frameworks to favor their industry's interests, including maintaining subsidies, resisting environmental regulations, and promoting favorable tax policies. This theory highlights how economic power and political influence intersect to shape energy policies, often at the expense of alternative energy sources and environmental concerns [12].

Central to the lobby-effect theory is the negative relationship between fossil fuel production and renewable energy development, which is frequently used in empirical studies as an indicator of the lobby effect, measuring how fossil fuel production inhibits renewable energy growth. Studies by Ankrah and Lin [12], Aguirre and Ibikunle [13], Pfeiffer and Mulder [42], and Sovacool [43], have used this relationship to validate the theory, demonstrating that increases in fossil fuel production can undermine clean energy initiatives.

The lobby effect theory further emphasizes the concept of "policy lock-ins," where the fossil fuel industry's influence creates structural barriers that discourage governments from implementing progressive energy policies [12,42]. By framing environmental regulations as threats to economic stability, job security, and affordable energy access, fossil fuel companies influence policymakers to delay or compromise on ambitious climate action [15,44]. This obstructive influence reinforces the dominance of fossil fuels and slows down the adoption of renewable energy sources, as observed in developing oil-producing economies such as Ghana [12]. Although direct lobbying activities may be less visible compared to developed nations, the significance of fossil fuels within Ghana's economy

Table 2
Summary variables, supporting literature, and relevance to the study.

Variable	Description	Supporting Literature	Relevance to Study
Fossil Fuel Production	Directly represents the economic power and policy influence of the fossil fuel industry. High production often links to intensified lobbying to hinder renewable energy growth.	Aguirre and Ibikunle [13], Ankrah and Lin [12], Pfeiffer and Mulder [42], Sovacool [43]	Reflects the lobby effect theory's prediction of fossil fuel sectors resisting renewable energy policy. Indicates fossil fuel industry's influence on energy policy and renewable growth.
Trade Openness	Captures the economic dependency on fossil fuel-exporting economies, highlighting the effect of trade relations on renewable energy adoption.	Wu et al. [29], Ankrah and Lin [7], Damijan et al. [49]	Shows how trade ties with fossil fuel-producing countries reinforce fossil fuel reliance. In Ghana, trade connections impact the balance between renewable and nonrenewable energy investments.
Foreign Direct Investment (FDI)	Reflects the role of international capital in energy sector development. Can support renewables or reinforce fossil fuels depending on investment priorities.	Wu et al. [29], Ankrah and Lin [7], Pfeiffer and Mulder [42], Damijan et al. [47]	Indicates FDI's dual role: may foster renewable energy or slow transition by funding fossil projects. For Ghana, FDI insights reveal foreign investors' influence on energy landscape.
Financial Development	Represents the accessibility of capital for renewable energy projects. Advanced financial systems can support renewable energy but often resist due to fossil fuel interests.	Gyamfi et al. [20], Zhang et al. [27], Irfan et al. [19]	Examines how financial systems in Ghana can either enable or restrict renewable energy investments. Aligns with lobby effect theory by highlighting financial interests resisting energy transition.

leads to indirect resistance to renewable energy, making the country an ideal case study for applying the lobby effect theory.

The lobby-effect theory has also been applied to emerging economies in various contexts. For instance, in India and Indonesia, fossil fuel industries have resisted renewable energy policies by leveraging their economic and political influence to ensure continued investments in fossil infrastructure [45,46]. Such examples highlight the global applicability of the lobby effect theory in examining how fossil fuel interests can obstruct renewable energy progress across different socio-political landscapes.

It is worthing that the application of this theory is crucial for understanding the broader geopolitical and economic factors that slow down energy transitions in developing economies. Ankrah and Lin [12] further emphasize how lobbying influences not only domestic energy policies but also international trade dependencies and other economic issues, reinforcing fossil fuel production. Thus, the lobby effect theory is essential to this study as it contextualizes the choice of variables: fossil fuel production, trade openness, foreign direct investment (FDI), and financial development. Each of these variables represents aspects of economic power, policy influence, and market dynamics that impact renewable energy adoption, particularly in emerging oil-producing economies like Ghana. Table 2 confirms that these variables were selected based on their relevance to the lobby effect theory and supported by findings from existing literature.

2.4. Research gaps

It could be observed from the literature that a significant research gap lies in the disproportionate focus on case studies from advanced economies, such as the United States and European nations, leaving the dynamics of energy transitions in developing and emerging economies underexplored. This oversight limits our understanding of how lobbying activities influence energy transitions in environments where resistance is less overt and often obscured by systemic factors such as resource constraints and limited institutional capacity. Moreover, a methodological gap persists in the over-reliance on static frameworks that fail to capture the dynamic interplay between fossil fuel production and renewable energy adoption. While some of the studies employ sophisticated models to examine energy transitions, majority of them rarely utilize state-dependent, multivariate models capable of revealing transition probabilities and the nuanced shifts between renewable and nonrenewable energy states. The absence of such dynamic approaches hinders a deeper understanding of the evolving energy landscape and the conditions necessary to foster a successful transition. More importantly, there is a significant void in empirical estimations of these dynamics within an African context even though studies like Osei-Tutu et al. [6] and Agyekum and Nutakor [11] have explored renewable energy potential in Ghana. Specifically, they lack an in-depth examination of how fossil fuel production and lobbying activities actively hinder clean energy adoption. This study, therefore, fills a critical gap by employing advanced, multivariate modeling techniques to assess the interaction between fossil fuel dominance and renewable energy adoption in Ghana. We seek to contribute to the global discourse on sustainable energy transitions while addressing both the geographical and methodological gaps.

3. Methodology and data

This section provides an overview of the methodological approach, including a description of the applied model, the data collection process, and an operational definition of energy transition that guide the analysis.

3.1. The Markov-switching model

The Markov-switching model, introduced by Hamilton [48], is widely regarded in time series analysis as a powerful non-linear model, especially well-suited for data that undergoes transitions between distinct regimes. This model extends beyond traditional linear time series models by incorporating autoregressive (AR) processes within a framework that probabilistically determines state

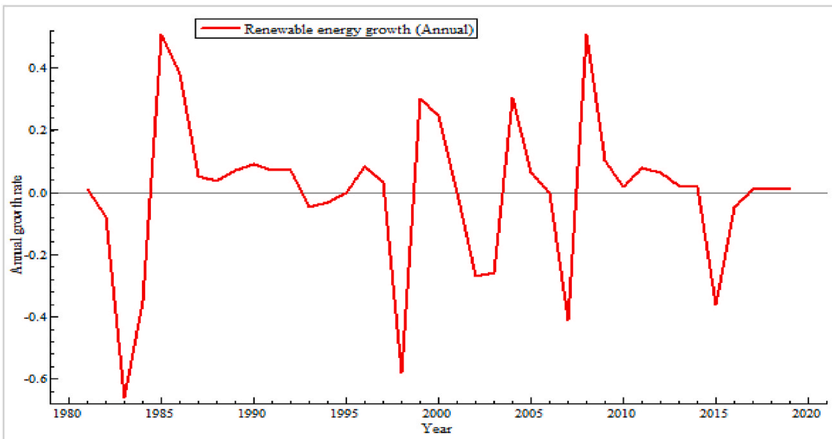

Fig. 2. Annual renewable energy growth.

shifts, making it highly adaptable to data series that change dynamically over time [48]. For instance, in the context of energy generation, Fig. 2 demonstrates the annual growth of renewable energy production in Ghana, illustrating observable periods of positive and negative growth rates. These fluctuations reveal the non-linear nature of the data, underscoring the need for a model that captures these shifts effectively.

Given the fluctuating nature of energy production data, applying a single, linear model may result in oversimplification, potentially masking critical patterns within the series. Models that accommodate structural changes, such as those proposed by Kuan [49], only allow for occasional and exogenous adjustments, which may fail to capture endogenous, state-dependent variations accurately. Alternative models, such as the threshold model by Balke and Fomby [50] and the random switching model by Quandt [51], offer partial solutions but often fall short in describing the intricate dynamics within data that naturally transitions between multiple regimes.

The Markov-switching model overcomes these limitations by allowing for random, regime-dependent changes [48]. It operates on the premise that the underlying process shifts probabilistically across a finite number of unobserved states, which are characterized by unique parameters, such as growth rates and volatility patterns. In scenarios where regime shifts are influenced by complex economic or environmental factors, the Markov-switching model provides a robust framework for estimating and forecasting these transitions [1].

In this study, the model's utility is further validated in its application to Ghana's energy transition dynamics, where renewable energy growth patterns are influenced by the presence and dominance of fossil fuel infrastructure [12]. This allows for a detailed examination of how Ghana's energy generation fluctuates between a "Renewable Energy State," and a "Nonrenewable Energy State." This two-regime framework aligns with our objective to differentiate between periods of renewable energy growth and periods dominated by fossil fuel reliance. More importantly, the choice of a two-regime model is to ensures that the model remains ergodic and that both states (renewable and fossil fuel) can transition back and forth with a measurable probability, reflecting a more realistic dynamic of Ghana's energy economy [12]. Note that in Markov models, ergodicity refers to the likelihood that the system will eventually transition between all states in the long run, given sufficient time [1]. A model with multiple regimes—such as three or more states—can pose ergodicity issues, where certain states may become "absorbing" or inaccessible over time, limiting the model's ability to capture full transitions across all states [48].

3.2. Model specification

Equation (1) represents a two-state Markov-switching regression model.

$$Y_t = X'_{t-i}\beta_{si} + \varepsilon_t, \quad \varepsilon_t \sim N(0, \delta^2) \tag{1}$$

where Y_t is the dependent variable, and X_t is a (k x 1) vector of exogenous variables, with $\beta_{st} = \beta_{1st} + \beta_0(1 - S_t)$. The model parameters under regime $S_t = i$ are denoted by $\phi_i = (\beta_i)$. Assuming state $S_t = i$ at time t, the conditional density for Y_t is given by Equation (2):

$$f(y|\ S_t = j, X_t Y_{t-1}; \phi) = \frac{1}{\sqrt{2\pi\delta}} EXP\left\{\frac{-(y_t - X_t\beta_j)^2}{2\delta^2}\right\} \tag{2}$$

The state variable S_t follows a Markov chain, independent of the past observations on y_t or current and previous x_t. Consequently, the probability for state variable S_t to be equivalent to a certain value j are defined by Equation (3):

$$P\{s_t = j|\ s_{t-1}, s_{t-2} = k, \ldots\ldots X_t\} = P\{s_t = j|\ s_{t-1} = i\} = P_{ij} \tag{3}$$

For a Markov chain with N states, the transition probabilities are specified by Equation (4):

$$\{P_{ij}\}_{i,j=1,2\ldots,N} \tag{4}$$

In a two-state Markov-switching model, these transition probabilities can be organized in a matrix as shown in Equation (5):

$$P = \begin{bmatrix} P_{00} & 1 - P_{11} \\ 1 - P_{00} & P_{11} \end{bmatrix} \tag{5}$$

All elements of P are nonnegative and sum to 1. A $P_{00} = 1$ suggests a zero probability of transitioning to state 1, making state 0 an absorbing state, meaning that the model is reducible. If $P_{00} < 1$ and $P_{11<1}$, the model is irreducible and ergodic [52].

Parameters ϕ and P_{ij} represent population parameters, with Vector θ encapsulating these terms. The estimation of θ is based on the observations in y_t. Even with known θ, the exact state process remains unknown. The researcher's inference on state variable s_t is represented by $P\{s_t = j|X_t; \varnothing\}$. This supports the conditional probability given by the researcher to the probability of ith observation formed by the j state. These conditional probabilities are denoted as: $P\{s_t = j|X_t; \theta\}$, for j = 1, 2, 3 … N, which can be depicted as $\vartheta_{t|\ t}$.

Forecasting the likelihood of state j in year t + 1, based on observation in year t, involves vector $\vartheta_{t+1|\ t}$. The j element of this vector is represented by $P\{s_{t+1} = j|X_t; \theta\}$. The optimal forecast and inference across the sample are derived by iterating Equations (6) and (7).

$$\vartheta_{t|t} = \frac{(\vartheta_{t|t-1} \ \delta\eta_t)}{I'(\vartheta_{t|t-1} \ \delta\eta_t)} \tag{6}$$

$$\vartheta_{t+1|t} = P\vartheta_{t|t} \tag{7}$$

where δ symbolizes an element-by-element multiplication and P represent an (N × N) transition matrix. The vector I is an (N × 1) vector of ones; η is N × 1 vector with its j-th element being conditional density function. Note that Equation (8) defines the conditional density function for the j-th element: $f(y_t = j|s_t = j, X_t; \phi)$ (8)

The log-likelihood for observed data, evaluated at parameter θ, is calculated using the formular in Equation (9):

$$\psi(\theta) = \sum_{t=1}^{T}; \ \theta \tag{9}$$

Where $f(y_t|X_t; \ \theta) \ = I'(\vartheta_{logf(y_t|X_t t|t-1}).$

The state variable in the Markov model accounts for random and regular changes in model structures, as the characteristics of X_t are defined by the features of the state variable and innovations. Furthermore, the persistence of a particular state within the model is determined by the transition probabilities, a concept detailed by Goodwin (1993).

Thus, the empirical estimation is described in Equation (10), which represents the primary regression framework for this study:

$$dRE_t = a_{sj} + \varpi_{isj} dRE_{t-1} + \beta_{1sj} dFFUEL_t + \beta_{2sj} dTRADE_t + \beta_{3sj} dFDI_t + \beta_{4sj} dFD_t + \mathcal{E}_{tsj} \tag{10}$$

where *RE* denotes electricity from renewable sources, and *FFUEL* from nonrenewable (fossil fuel) sources. *TRADE, FDI,* and *FD* represent Trade Openness, Foreign Direct Investment (net inflows), and Financial Development, respectively. These control variables are country-specific and are selected based on established empirically relationship established (See Table 2 in section 2.3). The state-dependent constant term is a_{sj}, whereas $\varpi_{isj}, \beta_{1sj}, \ldots., \beta_{4sj}$ are the corresponding coefficients of the determinants. The lag of *RE* in the model in the model allows for gradual adjustment post-state change, with coefficients determining shock duration in each state [52]. It is worth noting that the estimation process in this study involves a stepwise approach, with each model iteration incorporating additional variables. This process begins with a univariate model (Model 1), then sequentially introduces fossil fuel production, trade openness, FDI, and financial development to assess their individual and combined impacts on renewable energy adoption. Following the Ankrah et al. [1], a general description of the modeling process is simplified in Fig. 3

3.3. Operational definition of renewable energy and fossil fuel states

We define energy transition in line with the International Renewable Energy Agency [53], which emphasizes a shift in the energy sector from reliance on fossil-based sources to renewable, cleaner energy. This transition signifies a fundamental transformation in how economies generate and consume energy, moving away from traditional fossil fuels such as coal, oil, and natural gas toward

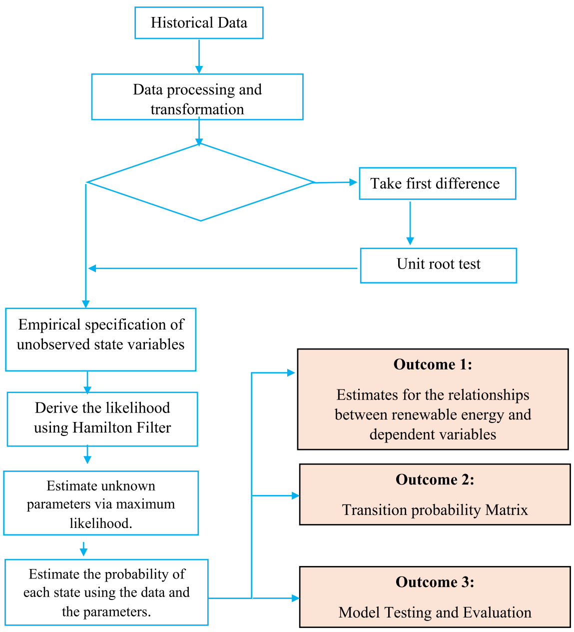

Fig. 3. Block diagram of the modeling procedure.

sources like solar, wind, hydroelectric, and geothermal power [12].

To operationalize this concept, an economy is classified as being in a "Renewable Energy State" at a given time (t) if, compared to the previous period (t-1), there is positive growth in renewable energy use. This growth may manifest as increased renewable production or a larger share of renewables in the total energy mix. For instance, a significant rise in hydropower generation or expanded capacity in other clean energy sources from one year to the next would place an economy in the Renewable Energy State. Conversely, an economy is classified as being in a "Nonrenewable Energy State" at time (t) if it shows a decline in renewable energy use relative to the previous period. This could involve a reduction in renewable production, a slowdown in renewable infrastructure installation, or a decreased share of renewables in the energy mix. This classification allows for an assessment of the energy sector's progress or regression toward sustainable energy, while recognizing that economies may transition between these states based on economic conditions.

3.4. Data

We employed annual data spanning from 1980 to 2019 to capture long-term trends in Ghana's energy sector. Table 3 below summarizes the variables, their definitions, and data sources.

Each variable underwent logarithmic transformation to address extremes and reduce the impact of outliers, following the methodology of Lin et al. [54]. Given that the Markov-switching model requires stationary series, unit root tests were conducted to ensure data suitability [51]. The Augmented Dickey-Fuller (ADF) test, a standard approach in time series analysis, was applied to each variable to verify stationarity. This test checks for unit roots by evaluating the null hypothesis that a series is non-stationary under three conditions: with a constant, with constant and trend, and without constant and trend [55]. We applied each condition to determine if the series was mean-reverting, trend-stationary, or a pure random walk. The decision criterion for stationarity relied on comparing the ADF test statistic to critical values and observing p-values, with significance determined at a 5 % level. If the test statistic was more negative than the critical value or if the p-value was below 0.05, we rejected the null hypothesis, indicating a stationary series. For series that were non-stationary at levels, we applied first differencing to achieve stationarity, thereby removing any inherent trend or seasonality. After differencing, each series was re-tested using the ADF method, and the results confirmed that all variables became stationary after first differencing, as shown in Table 3. These steps were crucial in preparing the data for the Markov-switching model, ensuring it met the assumptions necessary for analyzing regime shifts and transition probabilities.

4. Results and findings

This section presents the results of the various estimations, including unit root tests, autoregressive lag structure determination, and the outcomes from the Markov-switching model.

4.1. Unit root test

The unit root test, as shown in Table 4, confirms that none of the time series variables are stationary at levels. However, they achieve stationarity upon taking their first differences, validating their suitability for the analysis.

4.2. Autoregressive lag Structure

The "exogenous predetermined variables in the model often contain the lag of the dependent variable" [12]. This lag ensures a steady adjustment after the process changes state [55]. In determining a suitable specification order for estimation, a step-by-step approach to the assessment of different autoregressive lag structures is taken. It could be observed that the first and second order specifications affirm nonlinearity but fail the test of normality, while the third order passes both the normality and nonlinearity tests (see Table 5). The graphical analysis also shows that the third order fits the data well (top-left chart of Fig. 4). It is worth noting that fourth and fifth order specifications are omitted since they are reducible based on their transition matrix. They are not reported to conserve space. Thus, the third order structure is chosen for model specification due to its desirable statistical properties.

Table 3
Description of data.

Variable	Definition	Source
Renewable Energy - RE	Total electric power generated from renewable sources (Billion Kilowatt- hours).	US Energy Information Administration
Fossil Fuel - FFUEL	Total electric power generated from nonrenewable sources, particularly fossil fuels. It is measured in Billion Kilowatt- hours.	US Energy Information Administration
Trade Openness - TRADE	Trade openness is the "sum of exports and imports of goods and services measured as a share of gross domestic product."	World Development Indicators (WDI) of The World Bank
FDI – Foreign Direct Investment	Foreign direct investment, net inflows (% of GDP).	World Development Indicators (WDI) of The World Bank
FD	Financial development. Measured by "domestic credit to the private sector as a % of GDP."	World Development Indicators (WDI) of The World Bank

Table 4
Augmented Dickey-Fuller (ADF) Unit root test.

@ Level						
		LRE	LFFUEL	LTRADE	LFDI	LFD
With Constant	t-Statistic	−2.6469	−0.4910	−1.6980	−1.1439	−1.5209
	Prob.	0.0926	0.8823	0.4243	0.6885	0.5126
With Constant & Trend	t-Statistic	−3.1609	−2.2214	−1.3663	−2.5011	0.3354
	Prob.	0.1072	0.4650	0.8553	0.3260	0.9980
Without Constant & Trend	t-Statistic	0.3423	−1.0906	0.6670	−1.0285	0.7861
	Prob.	0.7787	0.2448	0.8559	0.2682	0.8788
@ First difference						
		d(LRE)	d(LFFUEL)	d(LTRADE)	d(LFDI)	d(LFD)
With Constant	t-Statistic	−5.6844	−6.1491	−6.2012	−5.7603	−6.6349
	Prob.	0.0000 ***	0.0000 ***	0.0000 ***	0.0000 ***	0.0000 ***
With Constant & Trend	t-Statistic	−5.6652	−6.1145	−8.0337	−5.0023	−6.3642
	Prob.	0.0002 ***	0.0001 ***	0.0000 ***	0.0013 ***	0.0000 ***
Without Constant & Trend	t-Statistic	−5.7242	−5.8891	−5.6278	−5.7662	−6.2919
	Prob.	0.0000 ***	0.0000 ***	0.0000 ***	0.0000 ***	0.0000 ***

Note.
1LRE: Logarithm of Renewable Energy.
2LFFUEL: Logarithm of Fossil Fuel Consumption.
3LTRADE: Logarithm of Trade Openness.
4LFDI: Logarithm of Foreign Direct Investment.
5LFD: Logarithm of Financial Development.

4.3. Impact on renewable energy and energy transition possibility

The estimation involves a step-by-step approach, progressively introducing regressors into the Markov model to distinctly ascertain the impact of each variable on renewable energy adoption and its transition probabilities. The analysis begins with a univariate model (Model 1), which initially includes no regressors. This is followed by a systematic introduction of additional variables in subsequent models (Models 2 to 5). Table 6 presents the results for each model, illustrating the varying impact of the introduced regressors on renewable energy adoption.

It is important to first note that the model's log-likelihood values increase as additional variables are introduced, indicating an improved fit to the observed data. The mean and variance of the dependent variable (DLRE) remain relatively stable across all models, suggesting consistent trends. The Akaike Information Criterion (AIC) values also decrease with each subsequent model, indicating improved model selection as more variables are introduced. The linearity LR-test results, with significant values, suggest nonlinearity. That is, the relationships might not be linear and more complex interactions might be at play. Additionally, the normality tests and ARCH 1-1 test help assess the distribution of errors and potential autocorrelation patterns. The sigma (standard deviation of error terms), indicates less variability, implying that the model is doing a relatively good job of explaining the variations in renewable energy consumption. The general conclusion for these statistics suggests that the more complex models, especially those introducing key variables related to fossil fuel influence, trade dynamics, and foreign direct investment, tend to better explain and predict the dynamics of energy transition in the power sector.

Moreover, the analysis of various models in the table reveals some insightful connections between different variables and renewable energy deployment. DLFFUEL, representing the first-differenced log of fossil fuel production, consistently shows a negative relationship with the first-differenced log of renewable energy (DLRE) across all models. The coefficients, ranging from −0.215 to −0.237 and statistically significant, confirm the lobby effect theory. The variable DLTRADE, which reflects changes in trade dynamics, exhibits mixed effects. In Model 3, it has a negative coefficient (−0.214) at 5 % significance, suggesting a potential adverse impact on energy transition. Conversely, in Model 4, the positive coefficient (0.158) at 10 % significance points to a potentially positive impact under different conditions, indicating that trade dynamics can have varying influences on the adoption of renewable energy technologies. Regarding foreign direct investment, represented by DLFDI, the findings are nuanced. While increased FDI is associated with decreased renewable energy adoption in some models, Model 4 shows a modest positive impact (coefficient of 0.013) at 10 %

Table 5
Statistics for autoregressive order selection.

Restriction	First order	Second order	Third order
Normality test	15.034**	6.181*	7.179
Linearity	30.002**	21.983**	32.984**
AIC	−0.491	−0.259	−0.769
Log-likelihood	23.336	21.790	32.839

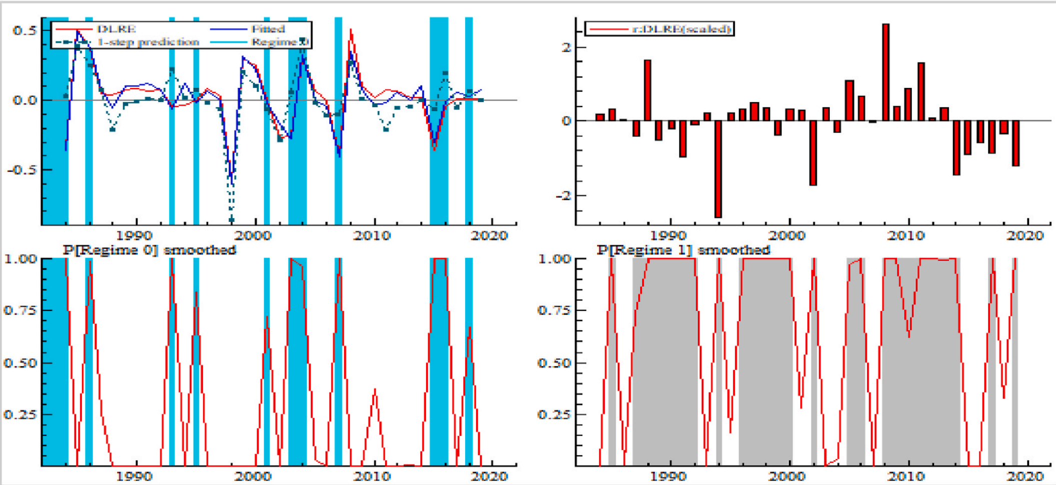

Fig. 4. Third-order graphic analysis. Note: DLRE represents the first difference log of renewable energy.

Table 6
Estimates from the Markov-switching model.

Independent Variables	Model 1	Model 2	Model 3	Model 4	Model 5
	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
DLFFUEL	–	−0.236*** (0.019)	−0.237*** (0.019)	−0.231*** (0.024)	−0.215*** (0.026)
DLTRADE	–	–	−0.032* (0.089)	−0.214* (0.118)	0.158* (0.125)
DLFDI	–	–	–	−0.019* (0.034)	0.013* (0.039)
DLFD	–	–	–	–	−0.121 (0.136)
Constant (0)	−0.130** (0.063)	−0.139*** (0.034)	−0.139*** (0.038)	−0.065** (0.028)	−0.043 (0.035)
Constant (1)	0.114*** (0.034)	0.147*** (0.016)	0.149*** (0.017)	0.163*** (0.024)	0.176*** (0.035)
DLRE_1(0)	0.235 (0.172)	0.109 (0.119)	0.089 (0.151)	0.099 (0.094)	0.124 (0.102)
DLRE_1(1)	−0.394** (0.154)	−0.279*** (0.068)	−0.278*** (0.068)	−0.315*** (0.082)	−0.360*** (0.095)
DLRE_2(0)	−0.277* (0.162)	−0.836*** (0.179)	−0.827** (0.202)	−0.216264 (0.125)	−0.303** (0.125)
DLRE_2(1)	−0.294** (0.125)	−0.240*** (0.054)	−0.249*** (0.058)	−0.260*** (0.073)	−0.290*** (0.089)
DLRE_3(0)	−0.451** (0.193)	−0.536*** (0.166)	−0.534*** (0.181)	−0.567*** (0.124)	−0.489*** (0.139)
DLRE_3(1)	−0.045 (0.140)	−0.259*** (0.057)	−0.263*** (0.058)	−0.165* (0.085)	−0.133 (0.094)
sigma	0.127*** (0.021)	0.0711*** (0.009)	0.071*** (0.009)	0.076*** (0.012)	0.079*** (0.012)
P_{00}	0.430* (0.236)	0.416** (0.181)	0.416** (0.184)	0.401* (0.197)	0.581* (0.327)
P_{01}	0.396 (0.259)	0.220*** (0.087)	0.223** (0.090)	0.406*** (0.140)	0.396* (0.197)
Model evaluation					
Log-likelihood	11.812	25.431	25.503	25.589	25.598
Mean (DLRE)	0.022	0.022	0.022	0.022	0.022
Var (DLRE)	0.052	0.051	0.051	0.051	0.051
AIC.T	−1.625	−28.863	−27.007	−22.778	−21.195
AIC	−0.045	−0.801	−0.750	−0.632	−0.589
Linearity LR-test Chi^2(6)	11.142*	21.521**	20.962**	18.265**	18.500**
Approximate upper bound:	[0.0462]	[0.0005]	[0.0006]	[0.0021]	[0.0019]
Normality test: Chi^2(2)	17.768	0.765	0.848	2.514	6.677
ARCH 1-1 test F (1,23)	0.096	1.279	1.399	0.015	0.025
Portmanteau (6): Chi^2(6)	0.541	13.099	11.915	6.773	14.064

Note.
1DLRE represent the first difference of the logarithm of renewable energy (the dependent variable).
2DLFFUEL: First difference of the logarithm of Fossil Fuel.
3DLTRADE: First difference of the logarithm of Trade Openness.
4DLFDI: First difference of the logarithm of Foreign Direct Investment.
5DLFD: First difference of the logarithm of Financial Development.
6***, **, * indicate 1 %, 5 %, and 10 % significance levels, respectively.
7Standard errors are based on numerical Hessian matrix. "Uniform probabilities were used to start recursion".
8Linearity LR-test $\chi 2$ 5; portmanteau (6) $\chi 2$ 6; normality test $\chi 2$ 2.
9Model 1 - Univariate (without regressors).
10. Model 2 - Multivariate (with DLFFUEL as a regressor).
11. Model 3 - Multivariate (DLFFUEL, DLTRADE as regressors).
12. Model 4 - Multivariate (DLFFUEL, DLTRADE, DLFDI as regressors).
13. Model 5 - Multivariate (DLFFUELL, DLTRADE, DLFDI, FD as regressors).

significance. This implies that FDI might sometimes lead to greater use of traditional energy sources over renewable ones, underlining the complex interplay between economic factors and energy transition. The impact of financial development (DLFD) is inconsequential, as indicated by the insignificant negative coefficient (−0.121) in Model 5.

Furthermore, constant (0) and constant (1) across Models 1–5 capture the base levels of renewable energy adoption in distinct regimes. Constant (0) represents the fossil fuel state, associated with negative growth in renewable energy, indicative of a major reliance on nonrenewable sources. On the contrary, Constant (1) denotes the renewable energy state, marked by positive renewable energy growth, reflecting a transition towards sustainable energy practices. The probabilities of transitioning between the states are shown by parameters P00 and P01 (See a complete transition probability matrix in Table 7). Moreover, the coefficients for DLRE_1, DLRE_2, and DLRE_3, which measure the lagged effects of renewable energy consumption, vary in their values and significance throughout regimes and models. This variation indicates that the relationship between past and current renewable energy production is regime-dependent, pointing to possible persistence or inertia in cleaner energy production patterns within specific regimes.

We proceed by examining how these estimates affect energy transition prospects. Table 6 displays the transition probability matrices for various models, illustrating the probability of transitioning between two regimes (Regime 0 and Regime 1) over time. In Model 1, a univariate model without regressors, the probability of remaining in Regime 0 is 43.02 %, whereas the probability of staying in Regime 1 is 60.35 %. These values suggest that Regime 1 (renewable energy state) is more stable than Regime 0 (fossil fuel state), indicating that once an economy transitions to renewable energy, it is more likely to persist in that state. Moreover, the probability of transitioning from Regime 0 to Regime 1 is 56.98 %, while the probability of transitioning from Regime 1 back to Regime 0 is 39.65 %. This asymmetry highlights a greater tendency for economies to move toward renewable energy, although the significant likelihood of reverting to the fossil fuel state underscores the fragility of this transition and the importance of sustained policy and market support.

As additional regressors are introduced in Models 2 to 5, these probabilities evolve, providing deeper insights into the factors influencing stability and transition. In Model 2, where DLFFUEL (fossil fuel production) is added, the probability of staying in Regime 0 decreases to 41.58 %, while the likelihood of transitioning to Regime 1 increases to 58.42 %. This suggests that fossil fuel production, despite its negative overall relationship with renewable energy, can initially drive awareness or diversification efforts that favor a shift toward renewables. This trend continues in Model 3 with the inclusion of DLTRADE (trade openness), further increasing the probability of transitioning to Regime 1. However, in Models 4 and 5, where DLFDI (foreign direct investment) and FD (financial development) are incorporated, the probability of remaining in Regime 0 increases significantly to 58.07 %, while the probability of transitioning to Regime 1 decreases. This shift implies that FDI, particularly when concentrated in fossil fuel infrastructure, reinforces existing dependencies and impedes renewable energy adoption, while financial development's limited influence may reflect systemic challenges in channeling capital toward renewables.

These probabilities reveal critical dynamics about the stability of each regime and the likelihood of energy transitions in both the short and long term. The higher stability of the renewable energy state (Regime 1) suggests a favorable outlook for long-term transitions, provided the right conditions are maintained. Conversely, the persistence of the fossil fuel state (Regime 0) in certain scenarios highlights the structural and economic barriers that must be addressed to ensure sustained progress. This nuanced understanding aligns with findings in existing literature, such as Ankrah and Lin [12], which document the inhibiting effects of fossil fuels on renewable energy development in Ghana. Additionally, studies like [42and43] emphasize the "lobby effect theory," where fossil fuel industries influence policy to hinder renewable energy growth. Brulle [44] further supports this with evidence of substantial lobbying expenditures aimed at obstructing climate change legislation, reinforcing the need for targeted interventions to overcome these barriers and enhance the stability of renewable energy transitions.

Table 7
Matrix for transition probabilities.

Model	Probability Matrix		
		Regime 0,t	Regime 1,t
Model 1	Regime 0,t+1	0.43024	0.39646
	Regime 1,t+1	0.56976	0.60354
Model 2	Regime 0,t+1	0.41582	0.22037
	Regime 1,t+1	0.58418	0.77963
Model 3	Regime 0,t+1	0.41634	0.22297
	Regime 1,t+1	0.58366	0.77703
Model 4		Regime 0,t	Regime 1,t
	Regime 0,t+1	0.58071	0.39589
	Regime 1,t+1	0.41929	0.60411
Model 5		Regime 0,t	Regime 1,t
	Regime 0,t+1	0.58071	0.39589
	Regime 1,t+1	0.41929	0.60411

Note.
1Model 1 - Univariate (without regressors).
2Model 2 - Multivariate (with DLFFUEL as a regressor).
3Model 3 - Multivariate (DLFFUEL, DLTRADE as regressors).
4Model 4 - Multivariate (DLFFUEL, DLTRADE, DLFDI as regressors).
5Model 5 - Multivariate (DLFFUELL, DLTRADE, DLFDI, FD as regressors).

5. Discussion and contribution of the study

The findings of this study offer a deeper understanding of the dynamics influencing Ghana's energy transition, shedding light on the intricate interplay between fossil fuel production and renewable energy adoption.

To begin with, Ghana's energy landscape reflects a strong imperative to transition towards renewable energy, driven by the need to address growing energy demands and environmental sustainability [56]. Despite notable structural changes, such as the shift from an exclusively hydro-based energy system to a hydro-thermal mix and increased private sector participation, the country remains significantly dependent on fossil fuels, particularly through thermal energy sources [7]. Recent developments, however, demonstrate a deliberate diversification of energy sources, highlighted by initiatives like Ghana's Renewable Energy Act and policies targeting a 10 % renewable energy penetration in the national energy mix [7]. Investments by companies such as Sunon Asogli Power Limited in solar energy further exemplify this shift [57]. These developments echo the insights of Lin and Ankrah [56] and Goodwin [58], who underscore the importance of aligning policy frameworks with market-driven strategies to sustain energy transitions. The stepwise regression models reinforce this trend, revealing that while fossil fuel production initially drives awareness and diversification, sustainable transitions require consistent policy and market interventions.

In addition to structural shifts, the role of foreign direct investment (FDI) emerges as a critical factor in shaping Ghana's energy transition. The findings suggest an interesting relationship between FDI and energy transition, where investments favor fossil fuel-based projects due to their established infrastructure and perceived stability. This reliance on fossil fuels is further reinforced by immediate economic returns, which overshadow the potential benefits of long-term investments in renewables. These observations align with Goodwin's [58] argument that investment flows heavily influence the direction of energy transitions in developing economies. Addressing this imbalance necessitates strategic policies that redirect FDI towards renewable energy through incentives and supportive regulatory frameworks. Such measures would enable Ghana to leverage FDI as a growth catalyst while gradually reducing fossil fuel dependency, aligning short-term economic needs with long-term sustainability objectives.

A notable result is the persistence of a negative relationship between fossil fuel production and renewable energy adoption which is a reflection of the difficulty of transitioning away from entrenched fossil fuel systems. This also underscores the challenges of balancing economic stability with sustainability, highlighting the need for a strategic and gradual shift. Ghana's approach to energy security demonstrates an attempt to address this balance through incremental strategies [7]. Policies such as the Renewable Energy Act of 2011, which introduced feed-in tariffs and investment incentives, and initiatives like the Scaling Solar Initiative, aimed at adding 500 MW of solar capacity, exemplify efforts to expand renewable energy capacity [59]. At the same time, investments in natural gas infrastructure, such as the Atuabo Gas Processing Plant, represent a transition from more carbon-intensive fuels to cleaner alternatives [60,61]. These strategies align with the perspectives of Sovacool [62] and Botrel [63], who advocate for dual approaches in developing economies, blending cleaner fossil fuels with renewables to achieve gradual energy transitions. The models' results further reinforce the need for sustained policy and market support to overcome structural barriers and ensure long-term progress.

Another noteworthy finding is the minimal, non-significant impact of financial development (FD) on renewable energy deployment, which seems counterintuitive given the potential of developed financial systems to facilitate investments in renewable technologies. This result may be explained by the prioritization of investments in traditional industries with quicker returns, as well as the lack of tailored financial mechanisms to support renewable energy projects. This aligns with Brunnschweiler's [68] argument that financial systems in many developing countries are not fully equipped to cater to the specific needs of renewable energy. It also suggests that the positive impacts of financial development observed in more advanced economies, such as those highlighted by Irfan et al. [19], may not directly translate to emerging economies like Ghana without targeted policy interventions.

The findings also reveal a mixed role for trade openness in renewable energy adoption, reflecting the complex dynamics of international trade. While trade openness can facilitate the import of renewable energy technologies, fostering technology transfer and reducing costs [49], it may also perpetuate reliance on fossil fuels through trade relationships with fossil fuel-exporting nations [29]. This duality suggests that the effectiveness of trade openness in promoting renewable energy transitions depends heavily on the nature of traded goods and trading partners, highlighting the importance of aligning trade policies with sustainable energy goals.

Theoretically, this study expands the scope of the lobby effect theory by illustrating how structural economic factors, such as FDI and fossil fuel dependencies, can impede renewable energy adoption in developing economies like Ghana. Unlike advanced economies, where direct lobbying is a dominant barrier [44], the Ghanaian context demonstrates the significance of indirect influences. This insight broadens the application of the lobby effect theory, suggesting the importance of accounting for economic structures and investment patterns that entrench fossil fuel dominance. Situating the theory within the unique challenges of an emerging oil-producing economy contributes to a deeper understanding of how economic dependencies shape energy transition pathways. From a practical standpoint, the findings highlight the need for recalibrated energy policies that foster a conducive environment for renewable energy investments. Policymakers are urged to implement targeted incentives to attract FDI into the renewable sector while adopting a hybrid energy strategy that integrates cleaner fossil fuels with renewables. This flexible approach ensures energy security while gradually transitioning toward sustainability. Additionally, the study challenges the predominant focus on direct lobbying as the primary obstacle to renewable energy adoption, underscoring the role of indirect factors like financial development and economic dependencies.

6. Broader implications and policy suggestions for emerging economies

While the findings of this study explain the case of Ghana, it holds broader implications for emerging economies. The ensuing section profiles these implications, particularly for Africa countries with similar economic-specific patterns.

6.1. Hybrid energy transition models in emerging economies

The energy transition strategy adopted by Ghana, which utilizes existing fossil fuel as a supportive backbone for the development of renewable energy, offers a viable model for other emerging economies, especially in Africa. This hybrid approach facilitates a gradual transition by leveraging the dependability of fossil fuel-based power to address the intermittent challenges often associated with renewable sources like solar and wind energy [64]. In many African nations, a complete overhaul of the existing energy systems might be economically and infrastructurally unfeasible. For instance, countries like Nigeria, with substantial investments in fossil fuel infrastructure, could benefit from this model, integrating renewables without discarding existing setups [64].

To effectively implement this strategy, policymakers in these nations should develop comprehensive energy policies that encourage the simultaneous development of both fossil fuel and renewable energy projects. This could include offering incentives for renewable energy investments, establishing regulatory frameworks that support hybrid energy projects, and facilitating public-private partnerships to fund these initiatives. Additionally, governments could invest in upskilling the workforce to manage and operate hybrid energy systems, ensuring a smooth transition while optimizing current energy assets. Through this hybrid approach, these countries can gradually shift towards more sustainable energy solutions without compromising their current energy stability and economic growth.

6.2. The strategic role of cleaner fossil fuels

Ghana's use of natural gas as a transitional fuel highlights the potential role of cleaner fossil fuels in supporting energy transitions in emerging economies. Natural gas, with its lower carbon emissions compared to coal and oil, offers a practical interim solution for countries aiming to reduce their reliance on more polluting fossil fuels while gradually building their renewable energy infrastructure. This approach is particularly relevant for African nations with significant natural gas reserves, such as Tanzania and Mozambique, as it allows these countries to leverage their natural resources to meet immediate energy needs while working toward long-term sustainability goals.

However, the transition strategy involving natural gas must be carefully managed to avoid the potential lock-in effects of investing in natural gas infrastructure. Such lock-ins could occur when large-scale investments in natural gas pipelines, processing plants, and power plants result in long-term dependency on this fossil fuel, delaying or complicating the shift to renewable energy sources. These effects are especially pronounced in contexts where economic incentives prioritize the continued use of existing infrastructure over more ambitious shifts toward renewables. Therefore, while natural gas offers immediate benefits, it is essential to ensure that investments in its infrastructure are designed with flexibility, allowing for integration with future renewable energy systems. Policy interventions should aim to mitigate these lock-in risks by promoting a dual approach: optimizing natural gas use while simultaneously accelerating investments in renewable energy. That is, governments should formulate policies that encourage the responsible exploration and extraction of natural gas, with environmental safeguards to minimize adverse ecological impacts. Investments in infrastructure should prioritize modular and adaptable technologies, such as hybrid power plants that combine natural gas and renewable sources, or pipelines that can later be repurposed for hydrogen distribution. These measures can ensure that natural gas infrastructure does not become an impediment to the ultimate goal of renewable energy dominance. Furthermore, regulatory frameworks must incentivize private sector involvement in natural gas projects while aligning these investments with renewable energy goals. For example, fiscal policies, such as carbon pricing or phased subsidies for renewables, can gradually shift the economic balance in favor of cleaner energy. Countries must also focus on expanding renewable energy capacity in tandem with natural gas utilization to avoid over-reliance on this transitional fuel.

6.3. Policy and investment directions for African economies

The energy transition observed in Ghana necessitates the formulation of well-thought-out policies and strategic investments across African economies. Policymakers are tasked with creating frameworks that facilitate the integration of renewable energy into existing grids, complemented by reliable fossil fuel-based power [65]. Ghana's experience demonstrates the potential for redirecting foreign direct investment (FDI) and trade flows toward renewable energy projects, moving beyond traditional fossil fuel extraction to prioritize renewable energy capacity development.

To achieve this, governments should offer financial incentives like tax breaks, subsidies, and feed-in tariffs, which lower costs and ensure predictable returns for investors. Moreover, simplified permitting processes and dedicated renewable energy agencies can reduce administrative bottlenecks, while public-private partnerships (PPPs) can attract both foreign and local investment by sharing risks and pooling resources. In addition, structured agreements, such as power purchase agreements and loan guarantees, provide additional security for investors. Green bonds and access to international climate funds, such as the Green Climate Fund, can also support renewable energy financing. Alongside these efforts, governments should prioritize investments in research and development (R&D) to foster local innovation and reduce technology costs. Similarly, upgrading infrastructure, including the development of smart grids and renewable energy zones, can enhance grid efficiency and reliability, encouraging more renewable energy projects.

Equally important is policy certainty; setting clear, long-term renewable energy targets and maintaining stable regulatory frameworks are crucial for ensuring predictable market conditions and boosting investor confidence. Through these strategies cohesively, African economies can create a robust investment climate for renewable energy, address pressing energy challenges, and promote sustainable economic growth while aligning with global environmental goals.

6.4. Fostering local participation and technological innovation

Ghana's approach to its energy transition, emphasizing local participation and innovation in renewable energy [66], can inspire similar developments across Africa. Actively engaging local communities and industries in renewable energy projects like solar and wind can foster local expertise and create new economic opportunities. South Africa's success in the solar energy sector exemplifies the potential benefits of investing in local renewable energy industries [67]. This approach can drive the growth of a sustainable energy sector that balances environmental considerations with economic benefits, leading to job creation and technological advancements.

To encourage this, policymakers should design and implement policies that support local enterprise development in the renewable energy sector. This could involve providing subsidies or tax incentives for local renewable energy companies, creating favorable conditions for start-ups, and establishing training programs to develop skills in renewable energy technologies. Additionally, governments could promote research and development in local universities and institutes, fostering innovation and the development of home-grown technologies. With priority on local participation and innovation, African countries can build resilient and self-sustaining energy sectors that contribute to their overall economic growth and environmental sustainability.

7. Conclusion

This study presents a framework for understanding the impact of the fossil fuel industry on renewable energy deployment in developing economies, with Ghana as a case study. Given limited data across the entire energy landscape, the analysis focuses on the electricity sector, a key area often at the forefront of energy transition efforts. A two-regime Markov-switching model was applied to data from 1980 to 2019, identifying shifts between energy states and estimating associated transition probabilities.

The investigation involves a stepwise approach across multiple Markov-switching models: Model 1, a univariate model without regressors; Model 2, a multivariate model incorporating fossil fuel production; Model 3, which adds trade openness; Model 4, which includes foreign direct investment (FDI); and Model 5, a comprehensive model featuring fossil fuel production, trade openness, FDI, and financial development as regressors.

The findings reveal a consistent negative relationship between fossil fuel production and renewable energy deployment, with coefficients ranging from −0.215 to −0.237, aligning with the lobby effect theory. Trade openness has varied effects on renewable energy deployment, showing both negative and positive influences. FDI introduces a complex influence on renewable energy, as increased FDI sometimes leads to greater use of traditional energy sources over renewable ones. Financial development shows minimal, statistically insignificant effects on renewable energy adoption. In terms of the impact on energy transition, we found a 39.65 % likelihood of transitioning to a renewable state, while remaining in the same state holds a 60.35 % probability. The inclusion of fossil fuel production in the model raises the likelihood of transition to 58.42 %, a trend which continues with the addition of trade openness. Interestingly, foreign direct investment markedly decreases the likelihood of transitioning to renewable energy state to approximately 42 %. These dynamics reflect Ghana's energy landscape as it contends with the challenges of balancing energy security, economic development, foreign investment priorities, and environmental sustainability.

These findings underscore the intricate dynamics between fossil fuel reliance and renewable energy transition in emerging economies, offering crucial understanding to balance immediate energy demands with long-term sustainability goals. Theoretically, it highlights the need to broaden the scope of the lobby effect theory to consider not only direct lobbying efforts but also the economic conditions and investment patterns that support fossil fuel dominance.

Generally, the present study makes key contributions to existing literature by applying a robust empirical approach to enhance traditional methodologies. Additionally, focusing on Ghana adds to the limited empirical work on emerging economies, providing a more inclusive view of global energy transition challenges. While these findings provide insights specific to Ghana, they hold broader implications for countries with similar economic structures. However, caution is necessary in generalizing these results; comparative studies across different nations would further clarify whether these insights hold universal relevance or are context specific.

Despite these valuable contributions, this study has limitations that point to promising avenues for further research. To start with, the focus on the electricity sector excludes critical areas such as transportation and others, thereby narrowing the scope of conclusions about broader energy transition prospects. Moreover, the generalized treatment of foreign direct investment (FDI) overlooks sector-specific nuances, potentially masking the distinct effects of energy-related versus non-energy-related FDI. Again, data limitations, a common challenge in emerging economies, prevented the inclusion of essential factors such as geographic conditions, infrastructure quality, and technological readiness, which are key elements influencing renewable energy adoption. Furthermore, the reliance on fossil fuel consumption (FFUEL) as a proxy for the lobby effect provides insights into fossil fuel dependency but falls short of capturing direct lobbying activities or political influence. Thus, future research could address these gaps by incorporating sectoral FDI data, direct lobbying metrics, and more comprehensive assessments of infrastructure and technology. Additionally, exploring targeted financial reforms becomes imperative in light of the minimal, non-significant impact of financial development (FD) on renewable energy adoption in Ghana. Such reforms could align financial systems more effectively with energy transition goals, addressing barriers like high costs, limited incentives, and entrenched ties to fossil fuels.

CRediT authorship contribution statement

Isaac Ankrah: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Michael Appiah-Kubi:** Writing – original draft, Software, Methodology, Formal analysis, Conceptualization. **Eric Ofosu Antwi:** Writing – original draft, Investigation, Formal analysis, Conceptualization. **Ivy Drafor Amenyah:**

Supervision, Resources, Investigation, Formal analysis, Conceptualization. **Mohammed Musah:** Writing – original draft, Investigation, Formal analysis, Conceptualization. **Frank Gyimah Sackey:** Writing – original draft, Investigation, Formal analysis, Conceptualization. **Richard Asravor:** Writing – original draft, Investigation, Formal analysis, Conceptualization. **Isaiah Sikayena:** Project administration, Formal analysis, Conceptualization.

Data availability statement

The data used in this study will be made available on request.

Ethics declaration

Review and/or approval by an ethics committee as well as informed consent was not required for this study because this article did not involve any direct experimentation/studies on living beings.

Declaration of competing interest

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

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