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ENERGY POLITICS: GLOBAL PATTERNS AND LOCAL REALITIES

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PREFACE

Energy stands not merely as a fundamental driver of economic growth but as a central pillar of international relations, global security strategies, and societal development. This volume endeavors to provide a comprehensive analysis of the shifting dynamics of global energy politics and the unique realities emerging at local levels. Drawing upon contributions from diverse geographical and disciplinary perspectives, it offers an essential insight into the study of energy policies within the broader framework of international political economy.

The chapters compiled herein address core themes such as energy security, energy justice, technological transformation, and geopolitical restructuring, employing a multidimensional approach that extends beyond the confines of economic analysis to include social and environmental implications. In doing so, this book seeks to enhance readers' understanding of the complex interplay between global energy trends and local policy practices.

We extend our deepest gratitude to all contributors whose intellectual efforts and scholarly dedication have enriched the quality and breadth of this volume. We also express our sincere appreciation to Farabi Publishing House for its support and commitment to the advancement of academic knowledge through the dissemination of works of this nature.

It is our firm belief that this book will serve as a valuable reference for academics, policymakers, and all readers seeking to better comprehend the evolving landscape of global and local energy politics.

Editor
Prof. Dr. Maximiliano Martinez ORTIZ

August 2, 2025

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CONTEMPORARY DEBATES AND ENERGY POLICIES IN THE CONTEXT OF INTERNATIONAL POLITICAL ECONOMY

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INTRODUCTION

The contemporary global energy landscape represents a complex intersection of technological innovation, environmental imperatives, and geopolitical considerations that fundamentally reshape international political economy (Zahoor et al., 2024a). Energy policies have evolved from primarily domestic concerns focused on resource extraction and distribution to multifaceted international issues encompassing climate change mitigation, technological competition, and global governance structures (Nelson et al., 2025). The urgency of addressing climate change while maintaining energy security has created unprecedented challenges for policymakers worldwide, requiring sophisticated understanding of how energy decisions ripple through economic systems and political relationships (Yu & Shi, 2025a).

Picture 1. Introduction Scenario Scemation
Source: data' researcher and development

The significance of energy in international political economy extends beyond traditional concepts of resource dependency and energy security (Vikky Setiawan & Asih Handayani, 2025). Contemporary debates encompass questions of energy justice, technological sovereignty, and the democratic governance of energy transitions (Sun et al., 2025). These discussions occur within a rapidly evolving context where renewable energy technologies are becoming economically competitive with fossil fuels, while geopolitical tensions continue to influence energy supply chains and investment patterns (Sumual et al., 2025).

This chapter examines how contemporary energy policies reflect and reshape power dynamics within the international political economy (Subbanarasimha et al., 2025). The analysis focuses on three interconnected dimensions: the institutional frameworks governing international energy cooperation, the economic implications of energy transitions for different categories of states, and the emerging debates about energy justice and democratic participation in energy governance (Sitorus et al., 2025). Through this examination, the chapter seeks to illuminate how energy policies serve as both mirrors and shapers of broader transformations in global political and economic structures (Satria Yudha Pratama & Jati Waskito, 2025).

1. THEORETICAL FOUNDATIONS OF ENERGY IN INTERNATIONAL POLITICAL ECONOMY

The theoretical understanding of energy's role in international political economy draws from multiple disciplinary traditions, each offering distinct perspectives on how energy resources and policies influence global governance structures (Santana & Díaz-Fernández, 2023). Realist approaches emphasize energy as a strategic resource that enhances state power and creates dependencies that can be exploited for geopolitical advantage (Premananda, 2025). Empirical evidence reinforces this view: leading energy producers and consumers also rank among the highest in military investment (Al & Kaplan, 2025, p. 22).

Picture 2. Teorytical Fondation

Source: data' researcher and development

Liberal institutionalist theories offer alternative frameworks for understanding energy governance, emphasizing the potential for international cooperation to address shared energy challenges (Nelson et al., 2025). From this perspective, energy policies represent opportunities for creating positive-sum outcomes through technology sharing, coordinated investment in infrastructure, and multilateral governance mechanisms that can manage both energy security and environmental concerns (Maulana et al., 2025). The development of institutions such as the International Energy Agency and the International Renewable Energy Agency exemplifies this approach to energy governance through international cooperation (Koivunen et al., 2022).

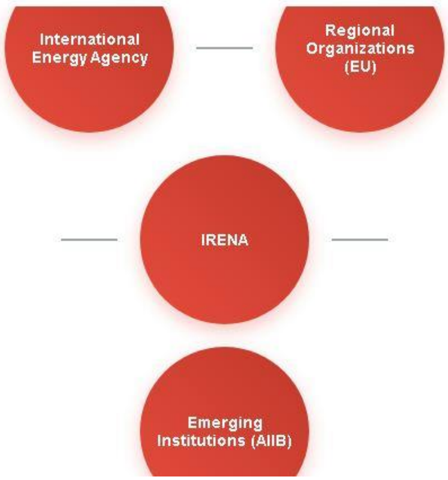
Critical political economy perspectives highlight how energy systems reflect and reproduce existing patterns of global inequality and power concentration (Hadiansyah & Yanwar, 2017). These approaches examine how energy policies can perpetuate dependencies between developed and developing countries, while also exploring how energy transitions might create opportunities for challenging existing hierarchies in the global economy (Guo & Polak, 2024). The concept of energy justice emerges from these critical perspectives, emphasizing the need to ensure that energy policies address distributional concerns and democratic participation rather than merely optimizing efficiency or security outcomes (Fenwick et al., 2024).

Contemporary theoretical developments increasingly recognize energy as a socio-technical system that cannot be understood purely through economic or political analysis (Djunaedi et al., 2025). This systems approach emphasizes the co-evolution of technological capabilities, institutional arrangements, and social practices in shaping energy transitions (Z. Chen, 2023). From this perspective, energy policies must address the complex interactions between technical possibilities, economic incentives, political constraints, and social acceptability that determine the success or failure of energy system transformations (Burema, 2025).

2. INSTITUTIONAL FRAMEWORKS AND GLOBAL ENERGY GOVERNANCE

The governance of global energy systems operates through multiple institutional layers, from bilateral agreements and regional organizations to multilateral institutions and global governance frameworks (Aqsa et al., 2025). The International Energy Agency, established in 1974 in response to the oil crisis, represents the most prominent example of multilateral energy governance, though its membership has historically been limited to developed countries. The agency's evolution from primarily focusing on oil security to encompassing renewable energy and climate concerns reflects broader transformations in global energy governance priorities.

Regional energy governance mechanisms have gained increasing importance as energy systems become more integrated across national boundaries (Aleisa et al., 2023). The European Union's energy policies exemplify how regional integration can create new forms of energy governance that transcend traditional state-centric approaches (Abonamah & Abdelhamid, 2024). The EU's energy transition policies demonstrate both the possibilities and limitations of coordinated regional approaches to energy governance, particularly in balancing national sovereignty concerns with collective action requirements (Zahoor et al., 2024b).



Picture 3. International Framworks
Source: data' researcher and development

The emergence of new institutional actors reflects changing power dynamics in global energy governance. The International Renewable Energy Agency, established in 2009, represents an attempt to create more inclusive global governance mechanisms that better reflect the interests of developing countries and the imperatives of sustainable development. Similarly, the increasing prominence of China and other emerging economies in global energy markets has led to the development of new institutional arrangements, such as the Asian Infrastructure Investment Bank, that challenge existing governance structures (Yu & Shi, 2025b).

Contemporary debates about energy governance increasingly focus on the democratic legitimacy and inclusiveness of existing institutions (Zakharia et al., 2023). Critics argue that current governance mechanisms reflect the interests of powerful states and corporations while marginalizing the voices of communities most affected by energy policies (Zainudin & Huda, 2024). These concerns have led to calls for more participatory approaches to energy governance that include civil society organizations, indigenous communities, and other stakeholders in decision-making processes (Welsandt et al., 2024).

The effectiveness of global energy governance mechanisms faces significant challenges from the intersection of energy security concerns, environmental imperatives, and geopolitical tensions (Sockalingam et al., 2025). The fragmentation of global governance architectures means that energy policies often reflect competing logics and priorities, making coordinated responses to shared challenges more difficult to achieve (Rexigel et al., 2024). The ongoing tensions between energy security and climate goals exemplify these governance challenges, as do the difficulties in creating inclusive governance mechanisms that can address the diverse needs and perspectives of different stakeholders (Park et al., 2024).

3. ECONOMIC DIMENSIONS OF ENERGY TRANSITIONS

The economic implications of energy transitions extend far beyond the energy sector itself, influencing patterns of economic development, international trade, and global competitiveness. The declining costs of renewable energy technologies have fundamentally altered the economic calculus of energy investments, creating new opportunities for countries that were previously disadvantaged by limited fossil fuel resources. However, the transition also creates significant economic disruptions for countries and regions that have built their economies around fossil fuel extraction and export (Nurjanah et al., 2025).

The concept of stranded assets has become central to understanding the economic dimensions of energy transitions. Fossil fuel reserves, extraction infrastructure, and power generation facilities face the risk of becoming economically unviable as renewable energy costs continue to decline and climate policies create additional costs for carbon-intensive activities. This dynamic creates complex economic and political challenges, as communities and countries dependent on fossil fuel industries must navigate the transition to new economic models while managing the social and political consequences of economic disruption (Naftaliev & Barabash, 2024).

Picture 4. Transision Framwork
Source: data' researcher and development

International trade patterns are being reshaped by energy transitions, with new forms of energy-related trade emerging alongside traditional patterns of fossil fuel trade. The growth of renewable energy technologies has created new patterns of technological dependencies, with countries like China achieving dominant positions in solar panel and battery manufacturing. These emerging trade patterns raise questions about technological sovereignty and the potential for new forms of energy dependencies to replace traditional fossil fuel dependencies (Maxwell et al., 2021).

The financing of energy transitions represents one of the most significant economic challenges facing the global community. The International Energy Agency estimates that achieving net-zero emissions will require annual clean energy investments of approximately four trillion dollars by 2030. This scale of investment requires fundamental changes in financial systems and international capital flows, with developing countries facing particular challenges in accessing the capital necessary for energy system transformations (Lim et al., 2024).

Economic debates about energy transitions increasingly focus on questions of distributive justice and the allocation of costs and benefits across different social groups and countries. The concept of a "just transition" has emerged as a framework for ensuring that the economic disruptions associated with energy transitions are managed in ways that protect vulnerable workers and communities. However, implementing just transition policies requires sophisticated understanding of local economic conditions and significant financial resources that many countries lack (Lichtenberger et al., 2025).

4. GEOPOLITICAL IMPLICATIONS OF ENERGY POLICY TRANSFORMATIONS

The geopolitical landscape of energy is undergoing fundamental transformation as renewable energy technologies become cost-competitive with fossil fuels and climate policies create new forms of international cooperation and competition., and the infrastructure necessary for energy system integration (Kozanitis & Nenciovici, 2023).

Picture 5. Implication Geopolitical

Source: data' researcher and development

The concept of energy interdependence is being redefined by technological changes that enable more distributed and diverse energy systems. While fossil fuel systems created particular patterns of dependency between resource-rich and resource-poor countries, renewable energy systems create different forms of interdependence based on technology supply chains, critical minerals, and the infrastructure necessary for system integration. These emerging patterns of interdependence have different geopolitical implications, potentially creating more opportunities for cooperation while also generating new sources of competition and conflict (Galano & Testa, 2025).

The rise of China as a dominant player in renewable energy manufacturing has created new geopolitical dynamics that challenge existing patterns of technological leadership and dependency. China's investments in renewable energy technologies and its Belt and Road Initiative represent attempts to reshape global energy systems in ways that enhance Chinese influence while providing development opportunities for participating countries. These developments have prompted responses from established powers, including efforts to develop alternative supply chains and technology partnerships that can compete with Chinese offerings (Fitria et al., 2024).

Climate diplomacy has emerged as a new dimension of energy geopolitics, with countries using climate commitments and clean energy investments as tools of international influence. The Paris Agreement and subsequent climate negotiations demonstrate how environmental concerns can create new forms of international cooperation, while also revealing how climate policies can become sources of international tension when they are perceived as threatening national economic interests or sovereignty (Deria & Wardani, 2022).

The geopolitical implications of energy transitions are complicated by the uneven pace of transformation across different regions and sectors. Countries that are early adopters of renewable energy technologies may gain competitive advantages, while countries that delay transitions may face increasing economic and political pressures. However, the transition also creates opportunities for countries that were previously marginalized in fossil fuel-based energy systems to play more prominent roles in renewable energy development and deployment (Yolanda et al., 2022).

5. CONTEMPORARY DEBATES IN ENERGY POLICY

Contemporary energy policy debates reflect broader tensions within international political economy between market-oriented approaches and state-led development strategies, between national sovereignty and international cooperation, and between efficiency-focused policies and equity-oriented approaches. These debates are occurring within a context of rapid technological change, increasing environmental pressures, and evolving geopolitical relationships that create both opportunities and constraints for policy innovation (Taufik et al., 2022).

Picture 6. Debates Contempory
Source: data' researcher and development

The debate over energy security versus environmental sustainability represents one of the most prominent contemporary policy discussions. Traditional approaches to energy security emphasized supply diversification, strategic reserves, and political relationships with resource-rich countries. However, climate change imperatives require rapid transitions away from fossil fuels, potentially creating short-term energy security vulnerabilities while pursuing long-term sustainability goals. Policymakers must navigate these tensions while maintaining public support for energy policies that may involve higher costs or reduced reliability during transition periods (Sri Utaminingsih et al., 2024).

Energy justice has emerged as a critical framework for evaluating energy policies, emphasizing the need to ensure that energy systems serve the needs of all social groups rather than merely optimizing aggregate outcomes. This perspective highlights how energy policies can reproduce or challenge existing patterns of social inequality, both within and between countries. Energy justice advocates argue for more participatory approaches to energy policy that include affected communities in decision-making processes and ensure that the benefits and costs of energy systems are distributed fairly (Siahaan et al., 2021).

The role of market mechanisms versus government intervention in driving energy transitions represents another major area of contemporary debate. Market-oriented approaches emphasize the importance of carbon pricing, removal of fossil fuel subsidies, and competitive markets in driving efficient energy transitions. However, critics argue that market mechanisms alone are insufficient to achieve the scale and speed of transformation necessary to address climate change, particularly in developing countries where market failures and capital constraints limit private investment in clean energy (Satyawan et al., 2021).

Debates about energy democracy focus on questions of ownership, control, and participation in energy systems. Advocates for energy democracy argue that centralized energy systems controlled by large corporations or state agencies are inherently undemocratic and advocate for more decentralized, community-controlled energy systems. These debates connect energy policy to broader questions about economic democracy and the appropriate role of different institutional arrangements in governing essential services (Prafitasari et al., 2021).

6. ENERGY POLICY CHALLENGES IN DEVELOPING COUNTRIES

Developing countries face distinctive challenges in formulating energy policies that can simultaneously address development needs, environmental concerns, and international pressures. Many developing countries must expand energy access to populations that currently lack reliable electricity while also contributing to global climate change mitigation efforts. This dual challenge requires sophisticated policy approaches that can achieve multiple objectives without creating unsustainable economic burdens (Özüdoğru, 2021).

Picture 7. Developing Country
Source: data' researcher and development

The concept of energy poverty highlights how lack of access to modern energy services constrains economic development and human welfare in many developing countries. Approximately 800 million people worldwide lack access to electricity, with the majority living in sub-Saharan Africa and parts of Asia. Addressing energy poverty requires significant infrastructure investments and supportive policy frameworks that can make energy services affordable and accessible to low-income populations (Najahah et al., 2022).

International development assistance for energy projects in developing countries has evolved significantly in response to climate change concerns, with many development agencies shifting funding priorities away from fossil fuel projects toward renewable energy and energy efficiency initiatives. However, this shift has created debates about the appropriateness of imposing environmental conditions on development assistance when developed countries built their economies using fossil fuels. These debates reflect broader tensions about differentiated responsibilities and the fairness of international climate policies (Insorio & Macandog, 2022).

The role of international private investment in developing country energy systems has become increasingly complex as investors face pressures to align their portfolios with climate goals while also seeking profitable investment opportunities. Many developing countries lack the regulatory frameworks and institutional capabilities necessary to attract large-scale private investment in energy infrastructure, creating financing gaps that must be addressed through innovative policy mechanisms and international cooperation (Hill, 2021).

Developing countries also face challenges related to technological capabilities and human capital development in the energy sector. The rapid pace of technological change in renewable energy requires continuous learning and adaptation, but many developing countries lack the educational institutions and research capabilities necessary to participate effectively in energy innovation. This creates dependencies on technology imports while limiting opportunities for domestic value creation in the energy sector (Hermita et al., 2022).

7.FUTURE DIRECTIONS AND POLICY IMPLICATIONS

The future trajectory of energy policies within international political economy will be shaped by several key trends and developments that are already beginning to emerge. Technological innovations in energy storage, smart grid systems, and energy management are creating new possibilities for energy system design that could fundamentally alter the economics and politics of energy. These technological developments may enable more decentralized and resilient energy systems while also creating new forms of economic opportunity and international cooperation (Hardiansyah & Mulyadi, 2022).

The integration of energy policies with broader sustainable development goals represents an important direction for future policy development. Rather than treating energy as a separate policy domain, there is increasing recognition that energy policies must be coordinated with policies addressing water resources, food security, urban development, and other interconnected challenges. This systems approach to policy development requires new forms of institutional coordination and planning capabilities that many countries currently lack (Febriati et al., 2022).

Picture 8. Future Direction
Source: data' researcher and development

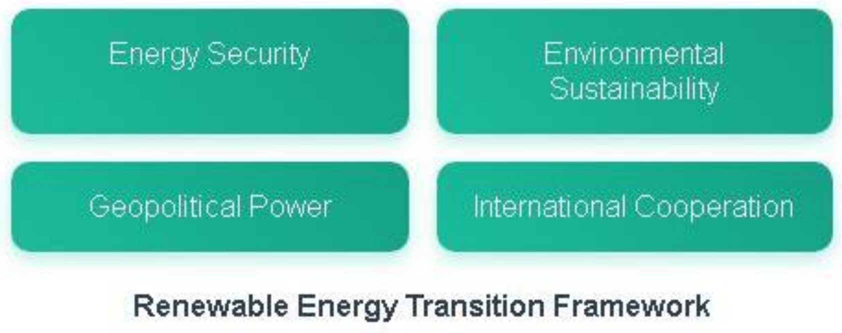
Climate change impacts on energy systems will require increasingly sophisticated adaptation strategies that can maintain energy security while managing the physical risks associated with extreme weather events, sea-level rise, and other climate impacts. These adaptation requirements will create new forms of international cooperation as countries share experiences and technologies for building climate-resilient energy infrastructure (X. Chen et al., 2023).

The democratization of energy systems through distributed generation, community ownership models, and participatory planning processes represents another important trend that could reshape energy governance. These developments create opportunities for more inclusive and equitable energy systems while also creating new challenges for system coordination and regulation. Policymakers will need to develop new approaches to energy governance that can balance the benefits of decentralization with the requirements for system reliability and coordination (Beardsley et al., 2021).

International cooperation mechanisms will need to evolve to address the changing nature of energy challenges and opportunities. This may require new institutional arrangements that can better integrate climate, development, and security concerns while also providing more inclusive participation opportunities for different stakeholders. The success of future energy policies will depend significantly on the ability to create governance mechanisms that can manage the complex interdependencies between energy systems, economic development, and environmental sustainability (Yadav et al., 2024).

CONCLUSION

The examination of contemporary debates and energy policies within the context of international political economy reveals a field characterized by rapid transformation, complex interdependencies, and fundamental challenges to existing governance structures. Energy policies have evolved from primarily domestic concerns to central elements of international relations, encompassing questions of security, development, environmental sustainability, and social justice that require unprecedented levels of international cooperation and coordination.



Picture 9. Abstract Overview
Source: data' researcher and development

The analysis presented in this chapter demonstrates that energy transitions represent more than technological or economic changes; they constitute fundamental transformations in the organization of global political and economic systems. The shift toward renewable energy systems creates new forms of interdependence while potentially disrupting existing patterns of power and influence that have characterized the international system since the industrial revolution. These transformations create both opportunities for more equitable and sustainable development pathways and risks of new forms of conflict and inequality.

The theoretical frameworks examined in this chapter suggest that understanding energy policies requires integration of multiple analytical perspectives that can address the complex interactions between technological possibilities, economic incentives, political constraints, and social dynamics. No single theoretical approach is sufficient to capture the full complexity of energy policy challenges, requiring synthetic approaches that can bridge different disciplinary traditions and analytical frameworks.

The institutional analysis reveals significant gaps between the scale and complexity of contemporary energy challenges and the capacity of existing governance mechanisms to address them effectively. While new institutions and governance arrangements are emerging, the fragmentation and competition between different institutional frameworks limits their effectiveness in addressing shared challenges. Future institutional development will need to focus on creating more inclusive, adaptive, and coordinated governance mechanisms.

The economic dimensions of energy transitions present both significant opportunities and substantial challenges for different categories of countries and social groups. While declining renewable energy costs create new development possibilities, the transition also threatens existing economic structures and may create new forms of dependency and inequality. Managing these economic transitions will require sophisticated policy interventions and international cooperation mechanisms that can address both efficiency and equity concerns.

The geopolitical implications of energy transitions are still unfolding, but early evidence suggests that renewable energy systems may create more complex and potentially more cooperative patterns of international interaction than fossil fuel systems. However, the transition period itself may be characterized by increased competition and tension as countries and companies compete for advantages in emerging energy markets and technologies.

Contemporary debates about energy justice, energy democracy, and just transitions reflect broader concerns about the inclusiveness and legitimacy of energy governance systems. These debates highlight the need for energy policies that address not only technical and economic considerations but also questions of participation, distribution, and procedural fairness. The resolution of these debates will significantly influence the political sustainability of energy transitions and their ultimate success in addressing climate and development challenges.

The analysis of developing country experiences demonstrates the importance of differentiated approaches to energy policy that recognize varying capabilities, priorities, and constraints. One-size-fits-all approaches to energy policy are unlikely to be effective given the diversity of economic, social, and political contexts within which energy policies must operate. International cooperation mechanisms must be designed to support diverse pathways toward sustainable energy systems rather than imposing uniform approaches.

Looking toward the future, the success of energy policies in addressing climate change while supporting economic development and social equity will depend on the ability to create governance mechanisms that can manage complex interdependencies and trade-offs. This will require new forms of international cooperation that can transcend traditional boundaries between domestic and international policy, between different sectors and policy domains, and between different types of stakeholders and institutions.

The transformation of global energy systems represents one of the defining challenges of the twenty-first century, with implications that extend far beyond the energy sector to encompass fundamental questions about economic development, political governance, and social organization. The policies developed to manage this transformation will play a crucial role in determining whether the global community can successfully address climate change while creating more equitable and sustainable patterns of development. The stakes could not be higher, and the need for sophisticated, coordinated, and inclusive approaches to energy policy has never been more urgent.

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CHAPTER 2
AMERICA AS AN ENERGY EPICENTER: A DIALOGUE BETWEEN THEORETICAL PERSPECTIVES AND NATIONAL POLICIES

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INTRODUCTION

Energy, as a critical component of economic growth and national security, has become a central focus in the study of international political economy. Energy constitutes not merely a catalyst for economic growth and a cornerstone of national security, but also a structural force within the international political economy. As Al and Kaplan (2025, p. 7) emphasize, it operates as a foundational mechanism in the consolidation of power and the accumulation of wealth, positioning it at the nexus of domestic priorities and global strategic interests. Its fundamental implications for power, interconnectedness, and global governance are the reasons why it has given rise to so many theoretical perspectives from which it is conceptualized. This article begins by examining the various theoretical perspectives that underpin the analysis of energy in international political economy, focusing specifically on energy policies in the Americas. The ultimate objective is to determine how the main theoretical paradigms (liberalism, constructivism, etc.) explain power dynamics, interdependence, and governance in the energy sector, both globally and regionally. The significance of this study is grounded in the inescapable truth that energy has ascended to a leading role in shaping national security, driving economic development, and sustaining geopolitical stability. This paradigm takes on even greater relevance in a region with an abundance of energy resources that, paradoxically, faces considerable challenges regarding equitable access, the sustainability of their exploitation, and fairness in their distribution. However, the wealth of resources does not exempt the region from a profound reflection on how these resources are managed; disparities in energy access persist, disproportionately affecting vulnerable communities and hindering the full realization of their human and productive potential. Likewise, sustainability emerges as an unavoidable requirement; the transition toward cleaner and more efficient sources is not only an environmental issue, but an imperative to ensure long-term viability and mitigate the effects of climate change, which are already significantly impacting the Americas.

1. INVESTIGATION

Understanding energy policies in the Americas requires an analysis that transcends unilateral explanations, recognizing the complexity of a sector where economic, political, and social interests are intertwined. Various theoretical currents offer interpretive frameworks to unravel this complexity.

From a liberal perspective, economic cooperation and interdependence are key elements in global energy governance.

Liberals such as Keohane and Nye (1977) introduced the concept of complex interdependence. This concept challenged the traditional realist view that emphasized competition between states and the pursuit of power by proposing that economic and social cooperation and interdependence are also defining characteristics of international relations. Key Ideas: Complex Interdependence focuses on how relations between states are becoming more intricate, marked by interdependence where the actions of one state can significantly impact other states. Furthermore, interdependence is not limited to relations between states; it involves non-state actors such as international organizations and transnational entities operating through multiple channels. And unlike realism, which views international politics as a hierarchy of dominant "powers," complex interdependence suggests that there is no clear order lacking an unequivocal hierarchy where cooperation is both possible and desirable. Therefore, the authors indicate that complex interdependence reduces the likelihood of conflict and fosters cooperation through international institutions. In this sense, energy is considered a market good, subject to the laws of supply and demand, where efficiency and liberalization are prioritized to guarantee supply and investment. In the Americas, this would translate into the promotion of open energy markets, free trade agreements, and the reduction of barriers to foreign investment in the sector.

Realism, on the other hand, prioritizes power and national security. For realists, such as Mearsheimer (2001), energy is a fundamental strategic resource in competition between states. The pursuit of energy security drives states to secure access to resources and diversify their sources, even through coercive means if necessary. In the American context, this could manifest itself in competition for control of reserves, the formation of strategic alliances to secure supply, or concern about energy dependence on external powers.

Constructivism, in contrast, emphasizes the social construction of energy policies, where ideas, norms, and identities influence the perception and management of energy. Wendt (1999) argues that structures of social interaction, rather than the distribution of material capabilities, shape the interests and identities of states. From this perspective, energy policies in the Americas are determined not only by economic or geopolitical factors, but also by narratives about sustainability, energy justice, resource sovereignty, and regional identity in relation to energy. For example, the push toward renewable energy in some Latin American countries could be interpreted as a response to an emerging social and political awareness about climate change and energy independence.

Other perspectives, such as Marxism or dependency theory, could focus on how the structure of the global capitalist system perpetuates inequalities in access to and distribution of energy resources. These theories would analyze how developed countries exert control over Latin America's energy resources, generating dependency and underdevelopment (Prebisch, 1950).

Rolf Linkohr's (2006) article delves into the unique and close relationship between energy and politics in Latin America, a connection that transcends mere economic logic. For the region, the possession of energy resources and state-owned companies such as Pemex and PDVSA represents a powerful symbol of national sovereignty, rooted in centuries of foreign exploitation. This perspective translates into the strategic use of oil and gas as tools of foreign policy and regional pressure, exemplified by the prioritization of domestic consumption of Argentine gas over exports to Chile, or Bolivia's refusal to sell gas to Chile in pursuit of access to the sea. It also exposes a duality in the politics of appropriation of energy resources. On the one hand, revenues derived from extraction grant states greater room for maneuver both internally and externally, financing public budgets and serving as a defensive barrier against the interference of multinationals. The nationalization of Mexican oil in 1938 is an emblematic case of this assertion of sovereignty. However, the author highlights the less favorable side of this nationalism. Despite their vast resource wealth, Latin American oil-producing countries often face high levels of poverty and unequal wealth distribution, with profits concentrated among elites. Furthermore, extractive industries generate few jobs, and their added value is limited without further processing. Linkohr argues that oil alone does not guarantee well-being unless accompanied by democracy, effective social policies, and a dynamic work ethic. The case of Venezuela illustrates how a welfare culture, fueled by oil revenues, can paralyze the development of other key sectors such as education, research, and industry, leading to a pernicious dependency and the paradox that the most prosperous countries are often energy importers. Another negative effect of energy nationalism is the inhibition of foreign investment and innovation. Mexico and Bolivia are examples of how the imposition of excessive taxes or nationalization can discourage the exploration of new deposits and access to technology, jeopardizing long-term energy self-sufficiency. Finally, it addresses future energy demand and the region's vast untapped potential. Although significant reserves of hydroelectricity, oil, gas, and coal exist, their exploitation faces environmental, technical, and political challenges. However, the author highlights significant opportunities in energy efficiency (e.g., solar showers in Brazil) and renewable sources: Brazil's success with sugarcane ethanol, the enormous untapped potential of solar and wind energy (especially in Patagonia), and the nascent but significant interest in nuclear energy (Mexico, Brazil, Argentina) and geothermal energy. Linkohr emphasizes that the development of these resources, combined with a unified regional stance on the sale of carbon emission rights, could generate significant capital and technology transfers, driving more sustainable and autonomous energy development for Latin America.

Isbell, P., & Steinberg, F. (2008) analyze how energy has become a central axis of Latin American regional geopolitics, transforming the balance between the state, national corporations, and international private companies. They identify the emergence of a new energy nationalism, driven both by the boom in hydrocarbon prices and by a growing distrust of the dynamics of economic globalization. The authors develop three main axes: the hemispheric geostrategic configuration, the role of producing states, and the tensions between energy sovereignty and global energy security. This article provides a strategic perspective that engages directly with the Americas as an Energy Epicenter, highlighting how the geopolitical valorization of Latin America responds not only to its resources but also to the way countries manage energy as a tool of power. Furthermore, it exposes how national decisions, especially in Venezuela and Brazil, not only affect their international projection but also the region's ability to position itself with alternative proposals in the global debate on energy transition and equity.

Bertinat P. (2016) proposes a structural critique of the current energy system, characterized by its concentration, commodification, and profound inequality. Through a multidisciplinary approach, the author argues that the energy transition cannot be limited to a technological or matrix change, but must be a political, social, and cultural process aimed at the "democratization of energy" and its recognition as a collective right. He also introduces the concept of "energy tongue twisters" as a roadmap for a just transition. This vision aligns with the perspective of super-strong sustainability (Gudynas), which questions the development paradigm based on infinite material growth and proposes a revaluation of energy as a common heritage. From this perspective, Latin America occupies a strategic position: not only as a direct exporter of energy (oil, gas, hydropower), but also as a virtual exporter through energy-intensive industries relocated from the global North. This condition reinforces its role as an energy epicenter, but also highlights a subordinate insertion into the international division of labor, where national policies often reproduce extractivist logic in the name of the right to development. The author argues for the need to build national energy policies consistent with an emancipatory vision, which recognize historical asymmetries and commit to a transition built from the territories, with citizen participation and socio-environmental justice. In this sense, the article offers a solid theoretical basis for rethinking Latin America's role not only as an energy provider, but also as a political entity capable of redefining the terms of the global energy transition.

In this article, Hancevic, Núñez, and Rosellón (n.d.) (2023) highlight the current state of the energy sector in Latin America and the Caribbean (LAC) in the context of climate change, assessing progress towards decarbonization in accordance with the commitments of the Paris Agreement. The article describes the energy structure of various countries, differentiating between hydrocarbon producers, economies with a high proportion of renewables, and import-dependent nations. It also identifies economic and political barriers that hinder the energy transition, such as poorly targeted subsidies or inadequate regulatory frameworks. Finally, the article proposes measures to overcome these challenges, such as strengthening energy governance, promoting clean electrification, and considering the social impacts of climate policies. The article on the energy sector in Latin America and the Caribbean analyzes the region's challenges and opportunities in the context of climate change, highlighting the need for effective public policies, decarbonization, and energy governance. The report "The Americas as an Energy Epicenter" presents a geopolitical perspective: how the region, despite not being the richest in fossil fuels, can become a key player thanks to its relative political stability, energy diversity, and export potential. The dialogue between theory and policy revolves around how LAC countries should translate their geopolitical potential into sustainable energy policies. The policy document emphasizes the need for regulatory frameworks and the elimination of inefficient subsidies, while the geopolitical approach underscores the importance of positioning themselves as a reliable supplier in a world in transition.

In his article, Malinovsky, N. A. (2024) analyzes the central role of energy in the current structural crisis of capitalism, framing his study within a process of phase change characterized by the energy transition, the climate emergency, and global geopolitical reconfiguration. Based on the Russia-Ukraine conflict, the author identifies a trend toward the deglobalization and regionalization of energy markets, which redefines value chains and investment flows in the sector. The energy transition, far from being a neutral or exclusively technical process, is presented as a new vector of capitalist accumulation, where major powers and transnational corporations seek to reposition themselves. In this context, Latin America, and particularly the lithium triangle (Argentina, Bolivia, Chile), emerges as a strategic territory and resource provider.

Furthermore, he posits a central hypothesis: the current energy transition process acts as a new niche for investment and capitalist expansion, driving the deglobalization and regionalization of markets and value chains. This reconfiguration, anticipated by the 2008 financial crisis, the COVID-19 pandemic, and the Russia-Ukraine (or Russia-NATO) war, is manifested in various energy trends that outline a new global economic structure. Among the main trends identified, the author highlights the deglobalization and regionalization of Russian gas through agreements with China (such as the Power of Siberia 1 and 2 pipelines) and the reconfiguration of the Russian oil market, which shifted from the European Union as the main buyer in 2022 to

China and India in 2023. Furthermore, there is a prevalence of "security or friendship" over "cheapest price" in energy procurement, exemplified by European subsidies to stop relying on Russian gas, despite the higher cost. Malinovsky points out that China, the European Union, and the United States are leading investment in clean energy, fostering a new commercial logic called nearshoring (regionalization of markets and relocation of industries). This not only drives a technological race for the development of clean energy but also intensifies the dispute over control of natural resources in regions such as Latin America and Africa, which are essential for this transition. The author emphasizes that this energy reconfiguration has put the climate change agenda on hold, with an increase in GHG emissions due to the substitution of Russian gas in Europe. At the same time, major oil companies have recorded historic profits at the expense of substantial state subsidies. In summary, Malinovsky argues that these transformations are symptoms of a deglobalization process characterized by the regionalization of energy markets and supply chains for strategic resources. This trend creates the possibility of exploring and exploiting new territories, which poses a risk for developing countries like Argentina of falling into a "defossilization accumulation" that does not benefit their own technological capabilities and energy sovereignty. The document concludes that the energy transition presents itself as a vector for a new process of capitalist accumulation, which prioritizes profit maximization over environmental protection. In this context of strategic uncertainty, the challenge lies in the capacity of the subaltern classes to direct change towards more just political, social and cultural structures, consolidating national and popular projects that allow for sovereign scientific and technological development, based on the control of natural resources and a redefinition of the relationship between humans and nature. (Malinovsky, N. A. 2024. 96-97)

The meeting of the Organization of American States (OAS 2024) highlights that the transition to clean, sustainable, and renewable energy in the Americas is a crucial imperative to combat climate change and build a prosperous and equitable future. This transition must be just and inclusive, ensuring the equitable distribution of benefits and obligations among all sectors of society, an approach supported by the mandates of the Ninth Summit of the Americas in 2022. As Javier Palummo Lantes, Special Rapporteur on

Economic, Social, Cultural, and Environmental Rights of the IACHR, rightly points out, "the transition to clean, sustainable, and renewable energy in the Americas must be approached from a perspective of justice and inclusion, recognizing the mistakes and challenges that have characterized the carbon-based economy" (OAS 2024-2). The region already has a predominantly renewable energy matrix (60%), which represents a solid starting point, but challenges remain in technological innovation, regulation, and the need for effective public-private collaboration to consolidate an equitable and resilient energy future for all.

Latin America's position as the energy epicenter of the 21st century cannot be understood without addressing the profound debate between the theoretical perspectives that guide the energy transition and the national policies that implement it. Within this framework, Leonardo E. Stanley's conclusions (2024, pp. 191–197) offer a key contribution to revealing the contradictions and opportunities facing the region. The author warns that the energy transition is irreversible, driven by technological, institutional, and cultural transformations. However, he emphasizes that not every transition is desirable if it is not fair and inclusive; it runs the risk of replicating historical inequalities in new "green" forms. This warning conflicts with technocratic and geopolitical narratives that celebrate Latin America's leading role in the provision of critical minerals without questioning their socio-environmental impacts.

Deakin A.'s (2024) article argues that Latin America is at an energy inflection point where geopolitics, regulatory reforms, and the need for electrification converge. Although it faces structural barriers such as collapsed transmission networks and high interest rates, the region has the potential to consolidate itself as a global energy leader. This dynamic aligns with this theoretical approach: energy development cannot be dissociated from each country's political framework, nor from its power structures and institutional capacity. The author emphasizes that an effective energy policy emerges from the synthesis of long-term vision and regulatory clarity, a central tension in the dialogue between theory and policy. Furthermore, he analyzes countries in the region, mentioning some such as Mexico, where the change in leadership with Sheinbaum could trigger a renewed opening to private capital and a greater push for renewables. This shift highlights how political ideologies can radically alter the energy environment, exemplifying the theory of institutional change dependent on political leadership. The United States, although not part of Latin America, its decisions on LNG exports directly affect Mexico and other countries. This confirms the idea of regional energy interdependence, which frames the "epicenter" approach as a dynamic, non-closed node. Meanwhile, Argentina's Milei paradox—climate denial combined with economic pragmatism—shows how energy policies can emerge even from contradictory ideological frameworks. In the Dominican Republic, its agile environment for renewable energy projects represents an efficient governance model that validates the hypothesis that energy development can prosper under conditions of clear regulation, technical capacity, and political will.

According to Alarcón et al. (2024), the IDB document, Watt's On: Energy for the Future, constitutes a valuable contribution to the analysis of Latin America and the Caribbean as an emerging energy epicenter. Through seven articles, it clearly exposes the structural challenges, technological innovations, and opportunities surrounding a just, inclusive, and sustainable energy transition. Its reading enriches our research by offering a concrete connection between public policies, regional integration, and new energy frontiers. We invite you to explore it as a key input to deepen the dialogue between theory and practice in energy matters.

2. FINDINGS

A systematic review of the academic literature reveals that each theoretical perspective offers a unique and valuable perspective for understanding the complex phenomena that characterize the energy sector in the Americas and globally.

From a liberal perspective, the importance of transnational cooperation in promoting energy initiatives and the formation of interconnected markets, such as regional electricity grids, becomes evident. This perspective also emphasizes the influence of international institutions in harmonizing regulations and enabling energy trade, crucial elements for the fluidity and efficiency of the system.

On the other hand, realism sheds light on the inherent competition for strategic energy resources, especially in oil and gas-rich regions. This perspective exposes the complex power dynamics between producer and consumer states, as well as the constant concern for national security regarding energy supply and infrastructure, fundamental pillars for the stability of any nation.

Constructivism, in turn, shows us how energy policies are intrinsically a social construction. Norms surrounding sustainability, the conception of energy as a human right, and the defense of sovereignty over natural resources are factors that, beyond cold economic or geopolitical logic, profoundly shape decision-making. A clear example of this is the shift toward energy transition in several Latin American countries, a change that stems from a profound transformation in ideas and values concerning the environment and development.

Malivesky's proposal takes on special relevance when problematizing Latin America's position as an energy epicenter, not only in its material dimension but also as a space of intense political and epistemic dispute. This critical reading prompts us to interrogate current national policies, often permeated by external interests, and to glimpse alternatives that integrate the theoretical perspectives of the Global South with sovereign development strategies, in pursuit of genuine autonomy.

In line with this vision, Stanley's perspective offers a multifaceted approach that invites us to rethink the role of the State, the architecture of international financing, and community participation in energy decisions. Latin America is at a pivotal moment for civilization: it has the choice of relegating itself to a subordinate provider of strategic resources or emerging as a leader in an energy transition that prioritizes life, equity, and sustainability.

Finally, Arthur Deakin's observations reinforce the notion that Latin America is emerging as a global energy epicenter, but not without facing significant institutional, financial, and infrastructure challenges. Consistent with our research findings, energy development in the region is not merely a technological or market issue, but a political construct deeply shaped by national leadership, levels of governance, and geopolitical positioning. This underscores that progress toward sustainable energy requires clear regulatory frameworks, political stability, and strong state capacity. Ultimately, the energy transition in Latin America is both a theoretical and deeply political issue.

CONCLUSION

The energy transition in the Americas transcends the mere pursuit of environmental sustainability; it represents an inescapable ethical and social imperative. To forge a truly equitable and resilient energy future, it is essential to establish inclusive social dialogue, address the structural injustices inherent in the current energy model, and incorporate a cross-cutting human rights approach into every phase of policymaking and implementation. Only through multisectoral collaboration, the promotion of national technological innovation, and the modernization of regulatory frameworks can we realize this collective commitment and move toward energy policies that are, in essence, more equitable and sustainable.

Energy policies in the Americas undoubtedly require a heterogeneous and interdisciplinary approach. It is evident that no single theoretical perspective can encompass the full range of challenges and opportunities that the energy sector presents in the region. Integrating the contributions of liberalism, which emphasizes cooperation and interdependence, and realism, which emphasizes competition and security, is essential. Constructivism, which emphasizes the role of ideas and norms, becomes essential for designing more robust strategies adapted to present and future challenges. Understanding energy dynamics is crucial, and this requires an approach that articulates the interactions between power, markets, institutions, and the social construction of policies. This perspective, which evokes Pérez Gamón C.'s (2023-2021) concept of "Active Citizenship," not only circumscribes membership in a state but also defines status based on the rights and duties inherent to citizens. Adopting this vision allows for the design of strategies that effectively promote energy security, sustainable development, and social justice at the regional level.

Ultimately, the energy transition in the Americas cannot be understood solely through ideal theoretical models; rather, it emerges from the living tension between global expectations and local political decisions. It is this dialogic, sometimes intrinsically conflictual, relationship between theory and practice that makes the Americas not just a stage, but a fundamental engine for the energy transformations of the 21st century. In this tension lies the true meaning of being an "epicenter": will we be a source of energy for others, or the nucleus of a truly emancipatory regional transformation?

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CHAPTER 3
ENERGY, URBAN DEVELOPMENT, AND WIND-SENSITIVE MICROCLIMATE STRATEGIES: PERSPECTIVES FROM RESIDENTIAL NEIGHBORHOODS IN IRAN

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INTRODUCTION

The increase in energy consumption to provide thermal comfort in buildings and its adverse effects is one of the major concerns in the field of building and energy (Zhang & Wang, 2025). By examining the rapid growth of urbanization and urban development, along with uncontrolled human interventions in the natural environment in developing countries—and by comparing traditional cities with contemporary urbanism—we can observe significant environmental consequences and widespread changes in energy consumption patterns at both the building unit scale and the broader spatial and structural framework of cities (Scott et al., 2021). The expansion of these building units, without considering climatic characteristics and with inefficient utilization of natural resources, has led to increased use of mechanical heating and cooling systems (Webb et al., 2020). In many developing countries, including Iran, the lack of attention to climate-responsive design principles in contemporary architecture and urban planning has resulted in substantial energy waste, increased pollutant emissions, and growing pressure on national energy networks (Mirmoghtadaei, 2013). In the past, Iranian cities considered ecological constraints such as water availability, nature-compatible development, energy conservation, the use of local materials, and the invention of effective methods for environmental sustainability, such as qanats, windcatchers, covered alleys, and artistic use of water and greenery to cool the air and create pleasant landscapes. The inclusion of gardens and courtyards in private homes, public spaces, and even around cities exemplified energy-efficient urban design (Bahadori, 2015). However, contemporary urban development, influenced by classical Western models and a blind imitation of stereotypical patterns that disregard local conditions and characteristics, has led to unsustainable conditions in cities and their surrounding areas (Franchi, 2004).

1. THE ROLE OF ARCHITECTURE AND URBAN DESIGN IN ENERGY EFFICIENCY

Architecture and urban design play a crucial role in addressing environmental challenges and energy demands. The physical form of space, the organization of mass and voids, the positioning of buildings, the dimensions of openings, shading, and the quality of façade surfaces are all factors that directly affect energy consumption and the thermal comfort of occupants (Zhang & Wang, 2025). For the first time, Lytton (1952) pointed out the effects of turbulent airflows near the ground surface. He also presented models to study and illustrate these effects. These models were later completed and refined by Velazy and Cohen in 1961 through the modification of Davenport's method. It was identified that pressure fluctuations on the windward surface of buildings are closely related to the behavior of the leeward side (Davenport, 1961). The form of a building can not only influence the stability and comfort of its occupants but also affect the intensity and direction of wind around the building, thereby influencing the comfort of pedestrians in adjacent spaces. Selecting an appropriate building shape can reduce aerodynamic forces on tall buildings by modifying wind force patterns around them (Ilgin & Gunel, 2002). Ahuja and Dalui investigated the interactive effects of openings and pilotis on the ground floor, podium levels, protrusions and recesses of entrance spaces, and chamfered corners at ground level on wind behavior and pedestrian comfort around buildings. They also proposed appropriate architectural solutions to moderate surrounding conditions and improve climatic comfort for pedestrians (Ahuja & Dalui, 2006).

Regarding the relationship between high-rise architecture and its significant effects on microclimate and especially wind behavior around buildings, many studies have been conducted. In 2008, a group of Japanese researchers focused on tools and techniques for modeling wind behavior around a building and its sidewalks. By analyzing results from wind tunnel tests, field measurements, and CFD simulations, they evaluated the accuracy of software outputs (Tominaga et al., 2008). Another study showed that changing the properties of certain elements and vegetation coverage (without altering the physical characteristics of buildings) can significantly reduce disturbing wind speeds and improve the climatic comfort of pedestrians around high-rise buildings (Kim & Leigh, 2013). In one recent study, climatic comfort from the perspective of wind behavior was assessed in a redeveloped square in Ireland. After collecting climatic data from the city of Dublin and modeling morphology affecting wind behavior using Envi-met software, the climatic comfort of the Grand Canal Square was examined, and zones outside the comfort range were identified. Finally, architectural proposals were offered to improve existing conditions (Szucs, 2013). Hong and Lin examined the impact of changes in the layout of buildings (placement) and tree arrangements around them on the climatic comfort of pedestrians. In this study, four building blocks surrounded by trees were placed in six different arrangements, and their surrounding wind behavior was evaluated (Hong & Lin, 2015). As a result, rethinking architectural and urban design based on climate-responsive principles is not only an environmental necessity but also a strategic approach to reducing energy consumption, enhancing urban resilience, and achieving sustainable and locally adapted development.

1.1 Purpose And Scope of the Chapter

This chapter is written with the aim of investigating the role of climate-responsive design in reducing energy consumption in high-rise residential buildings in urban fabrics of Iran, particularly in cold and windy regions. The main focus is on analyzing the role of components such as balconies as semi-open and static elements in facades, and their impact on natural ventilation, wind pressure reduction, and thermal performance optimization of buildings. In this regard, double-skin facades are examined as a design solution that can create an intermediate layer between exterior and interior spaces while optimally directing airflow. The current study, relying on computational fluid dynamics (CFD) simulations and parametric modeling, seeks to identify the factors affecting thermal comfort and energy-saving potential at various facade design levels through quantitative and qualitative analyses. The city of Hamedan, as an example of cold climate in Iran with its specific topographical and climatic characteristics, has been selected as the case study. The scope of this chapter goes beyond analyzing a single building element; it attempts to address the existing research gap at the intermediate scale (at the level of urban blocks and neighborhoods) - a scale often overlooked between the micro (individual building design) and macro (urban policy) approaches.

Emphasizing this scale can pave the way for developing strategies that are useful both in architectural design processes and urban planning, leading toward sustainable development, reduced dependence on fossil fuels, and enhanced livability of residential spaces in developing countries. Ultimately, this chapter proposes a framework for integrating climatic analysis, responsive facade design, and creative use of traditional elements in high-rise architecture, as a step toward shaping low-carbon, energy-efficient, and climate-adapted cities.

2. THE ENERGY–DEVELOPMENT NEXUS IN THE GLOBAL SOUTH

2.1 Energy Access, Demand Growth, And Development Imperatives

It is projected that in the coming years, two-thirds of the world's population will live in urban areas—an increase that, since 2015, has resulted in a net growth of approximately 2.4 billion people in urban populations, mainly in Asia and Africa (UN-Habitat, 2020). This rapid growth will place additional pressure on cities that are already struggling to provide clean, reliable, and affordable energy to their residents. For example, in 2012, only 58 percent of the urban population in low-income countries had access to electricity, and nearly 500 million people relied on polluting fuels such as wood and charcoal for cooking, an issue that leads to hundreds of thousands of premature deaths annually due to air pollution. Meanwhile, the fossil fuel-based development model pursued over recent decades in the Global North is no longer defensible, as its continuation is incompatible with global commitments to reduce and ultimately reverse the upward trend in carbon emissions.

Therefore, achieving new energy consumption models that are simultaneously sustainable, affordable, and compatible with urban population growth has become an urgent necessity (UN-Habitat, 2020). Energy, as a key infrastructure, has always served economic growth, human development, and the improvement of quality of life. From meeting basic needs such as food, heating, and lighting to contributing to health, income, education, and gender equality, there is extensive evidence that sustainable and secure access to energy carriers can directly impact individual and social well-being indicators (Pachauri, 2012). However, energy consumption patterns remain highly unequal across the world. Deep disparities exist in both the quality and quantity of access, between the Global North and South, between rich and poor populations, and between rural and urban communities. These inequalities not only reduce human well-being but also have damaging effects on the environment and hinder sustainable development progress (Pachauri, 2012). More than one-third of the global population, particularly in rural areas of developing countries, still lacks access to modern, reliable, and affordable energy. This situation constitutes a serious obstacle to economic and social development and remains one of the main barriers to achieving the Sustainable Development Goals. Under these circumstances, planning for the energy future in the Global South requires a vision beyond mere infrastructure expansion, one that integrates energy justice, climate responsiveness, and resilience into macro-level policymaking and urban design.

2.2 Iran's Energy Landscape in Brief

Iran, as one of the developing countries endowed with abundant fossil fuel resources, has faced deep challenges in energy consumption and efficiency in recent decades. According to international reports, the average annual energy consumption in Iran has grown by about 10%, which is significantly higher than the global average (Fereidani et al., 2021). Among the consuming sectors, buildings constitute a major share. Based on the energy balance sheet published by the Ministry of Energy, 40% of total energy consumption in Iran is related to the building sector, mostly in residential areas (Fereidani et al., 2021). Meanwhile, Iran's energy consumption in the building sector is about 2.5 times higher than the global average, making it a major contributor to CO_2 emissions (Zhang & Wang, 2025). One of the reasons for this high consumption level is the relatively low cost of energy, which has hindered the development of a culture of energy saving. Moreover, the average annual energy use in Iranian buildings ranges between 300 to 400 kWh per square meter, while in European countries it is approximately 120 kWh, a significant discrepancy that highlights the inefficiency of energy use in Iranian buildings (Zhang & Wang, 2025). In addition, Iran's urban structure, especially in dense urban fabrics, has a significant impact on microclimate conditions and energy demand. Increased density and the lack of climate-responsive design at the block and neighborhood scale have led to a substantial increase in demand for artificial cooling and heating in many Iranian cities (Karimimoshaver et al., 2021).

In this context, some studies emphasize that strategies such as optimizing building mass forms, designing open spaces, controlling solar radiation, and utilizing natural ventilation can directly contribute to reducing energy consumption (Karimimoshaver et al., 2021). However, most energy policies in Iran have either focused on large-scale infrastructure development or been implemented at the micro level (individual buildings), while there is a pressing need to focus on the intermediate scale, i.e., urban fabric. Therefore, rethinking energy consumption patterns, prioritizing climate-responsive design at the urban scale, and reforming consumption culture through interventions in the physical form and structure of cities are among the key strategies that can set Iran on the path to energy sustainability. Wind flow is one of the key factors in shaping thermal comfort, natural ventilation, and pollution control in urban and architectural spaces. Its interaction with the form, layout, orientation, and geometry of buildings can significantly improve or degrade the microclimatic conditions of the environment (Ng, 2012). In many studies, wind flow simulation has been used as an analytical tool to evaluate the climatic performance of buildings. For example, in Ranjbarian research (2022), using CFD simulation of a tall building in Tabriz, the effect of a double-skin façade on wind pressure on the outer skin and turbulence around the building was examined, and the results showed that the use of a double-skin façade led to a significant reduction in turbulence and improved ventilation in the intermediate layer of the façade.

Another study in Hamedan showed that by changing the location and dimensions of balconies on southern façades, natural ventilation in indoor spaces improved and airflow was more effectively guided. The best performance was achieved when the balconies were rectangular, enclosed on three sides, and asymmetrically placed on the building façade in the direction of prevailing wind. Moreover, morphological analysis shows that increased enclosure in urban spaces leads to channeled airflow and higher wind speed, whereas poor urban fabric design can cause stagnant airflow and increase surface temperature. Some sources also emphasize that by applying vernacular design principles, it is possible to provide effective ventilation without high-consumption mechanical equipment. In Bushehr, spatial design based on wind direction and the use of changing alleyway sections was done in such a way that increased pressure and wind speed from alley entrances to the inner space led to natural cooling (Bahadori, 1994).

In summary, the interaction between wind flow and spatial form is not only a tool for natural ventilation and enhancing thermal comfort, but also plays a fundamental role in reducing energy consumption, preventing pollutant accumulation, and promoting climatic adaptability in cities.

This becomes particularly important in the design of tall buildings, semi-open spaces, and dense street networks (Santamouris, 2013).

2.3 Architecture and Passive Ventilation

Natural Ventilation (Passive Ventilation) has long been one of the most effective passive design strategies in sustainable architecture, playing a vital role in providing thermal comfort and reducing reliance on mechanical systems. In Iran's hot, humid, or arid climates, traditional architects leveraged their understanding of the climate and intelligently utilized structural elements such as windcatchers, verandas, courtyards, and well-designed openings to facilitate effective natural ventilation in buildings. Research indicates that natural ventilation offers several advantages, including low implementation costs, zero energy consumption, minimal maintenance requirements, and enhanced physical and psychological well-being in living spaces. The primary objectives of this ventilation method include maintaining indoor air quality (1–2 ACH), heat removal (10–15 ACH), and improving thermal comfort through perceptible air movement (Omrani et al., 2017). In contemporary high-rise buildings, particularly in densely populated urban areas, balconies have emerged as one of the most effective elements for natural ventilation.

Studies show that balconies can significantly reduce wind pressure on facades, enhance single-sided ventilation, and lower cooling energy consumption. Additionally, semi-enclosed balconies at a zero-degree angle to the wind have been found to dramatically improve natural ventilation performance. In this context, architectural detailing—such as the orientation of openings, wing walls around balconies, and strategic window placement—also has a noticeable impact on ventilation quality. Findings suggest that adding a wing wall to a balcony and positioning it alongside double-glazed windows can improve indoor ventilation efficiency by up to 80%. Traditional Iranian architecture, particularly in central and southern regions, skillfully employed passive design techniques such as central courtyards, wind-responsive building orientations, and even the adjustment of alleyway widths. These simple yet effective measures remain relevant in contemporary design, offering significant energy savings and enhanced comfort (Zhang et al., 2024).

Ultimately, despite advancements in mechanical ventilation technologies, the effective use of natural ventilation is not only energy-efficient but also improves indoor air quality, reduces pollution, and enhances the spatial experience for occupants. This approach is particularly crucial for developing countries facing infrastructural and resource constraints, as it can play a key role in achieving sustainable architecture.

2.4 Urban Morphology and Air Movement

The form and physical structure of a city play a crucial role in shaping wind patterns, natural ventilation, and the distribution of pollutants in urban spaces. Key factors influencing airflow behavior include the street height-to-width ratio, block orientation, degree of enclosure, and building density. Nouri et al. (2024) further emphasize that urban form combined with high density and tall buildings disrupts urban wind flows, creating zones with excessively low or high wind speeds and reducing pollutant dispersion capacity, a critical issue in highly polluted urban areas. In specific climates like Bushehr, traditional urban fabrics with narrow alleys and optimal orientation toward prevailing winds create ideal conditions for natural ventilation. In such cases adjusting street cross-sections, angles, and building heights channels wind flow and improves natural ventilation. In summary, climate-responsive urban design, through the careful configuration of urban blocks and forms, can enhance thermal comfort, natural ventilation, and energy efficiency by strategically directing or mitigating wind flows.

2.5 Key Factors Influencing Natural Ventilation

Natural or passive ventilation is a process that uses natural forces such as wind and temperature differences to move air and cool interior spaces. Understanding the factors affecting this type of ventilation plays a key role in climate-responsive building design and energy efficiency (Givoni & Allard, 2006). One of the primary driving forces in natural ventilation is pressure difference caused by wind or temperature (Howard Sherman & Chan, 2006).

In this regard, it is stated that Natural ventilation can provide fresh air, help transfer internal odors and heat, assist in structural cooling, and reduce radiant heat. The main factor creating natural ventilation is pressure difference, which occurs for two reasons: 1) wind-induced pressure difference, 2) temperature-induced pressure difference (Awbi, 2016). This pressure difference may result from horizontal flow (wind) or vertical flow (thermal buoyancy).

Typically, in natural ventilation, the effect of wind force is greater than the effect of buoyancy force, and the dominant ventilation is through wind (Lomas, 2007). The type and position of openings is another influencing factor. The shape, height, and distribution of openings in walls can facilitate one-way or two-way ventilation (Oke, 1987). Air movement depends on proper placement of openings and passive design strategies. Natural ventilation can be one-way, two-way, stack-driven, or a combination. In addition, specific architectural elements such as wind towers, chimneys, windows, wing walls, double-skin facades, atriums, and ducts are among the tools that are effective in enhancing natural ventilation (Fathy, 1986). Finally, climate, building form, height, orientation, and urban density are also determining factors in the performance of natural ventilation (Oke, 1987). These components can significantly increase or decrease the efficiency of these systems by directing or controlling airflow (Howard Sherman & Chan, 2006).

2.6 Importance of Wind Flow in Reducing Cooling Demand

Natural wind flow is one of the most important driving forces in climate-responsive design to reduce the need for cooling in buildings, especially in hot, dry, and humid climates. Wind enhances indoor air movement, increases sweat evaporation on the skin, and improves thermal exchange, significantly elevating the sensation of coolness and thermal comfort (Heidari et al., 2024). According to studies, faster air movement can accelerate sweat evaporation and heat transfer from the body to the environment, resulting in improved thermal comfort and reduced demand for mechanical cooling. This effect becomes more critical in humid climates, where increased airflow also helps reduce indoor relative humidity. In a study by Karimimoshaver et al. (2023), it is emphasized that natural ventilation is one of the key strategies to reduce cooling loads of electric HVAC systems and optimize energy consumption in buildings, with architectural elements such as balconies playing a vital role in facilitating airflow.

Similarly, CFD simulations in the study by Renjbarian demonstrate that by controlling the aerodynamic behavior of wind around high-rise buildings, it is possible to adjust pressure and suction zones, thereby enabling effective natural ventilation and reducing cooling loads. Furthermore, the creation of optimal wind pathways in urban areas and avoiding obstruction by building masses is one of the determining factors in improving the effectiveness of passive cooling. Morphological analyses also confirm that appropriate configuration of building blocks can enhance wind generation around structures, thus helping to reduce cooling energy consumption. Additionally, wind-responsive urban design, through appropriate spacing between buildings, proper orientation, and varied building heights, can create natural ventilation in streets, preventing excessive heat buildup and reducing cooling loads in surrounding buildings. In conclusion, wind flow—by facilitating natural ventilation, non-mechanical cooling, and improved thermal comfort—is a key factor in reducing cooling energy consumption and enabling the design of sustainable buildings in hot and windy climates (Zheng et al., 2021).

3. CASE STUDY: RESIDENTIAL NEIGHBORHOODS IN IRAN

3.1 Methodology: Simulation And Spatial Analysis Tools

In studies related to climate-responsive design, natural ventilation, and wind flow analysis in urban environments, advanced numerical simulation and spatial analysis tools play a pivotal role in evaluating the climatic performance of spaces prior to implementation. These tools enable designers to examine and optimize airflow behavior, thermal comfort, and the efficiency of various architectural and urban forms during the design stages.

One of the most widely used numerical simulation methods in this field is Computational Fluid Dynamics (CFD), which serves as a primary tool in many studies analyzing wind flow and natural ventilation. For example:

- In Nouri et al. (2024), CFD-based simulation is the core methodology. The method used in this study is based on a CFD approach, which includes the analysis of systems such as fluid flow, heat transfer, and associated phenomena.

- Karimimoshaver et al. (2023) utilized a set of specialized software tools including ANSYS SpaceClaim, ANSYS Meshing, ANSYS Fluent, and CFD-Post to simulate natural ventilation through balconies in high-rise buildings.

Alongside CFD, ENVI-met has been widely employed as a key tool for evaluating outdoor thermal comfort. In the research of Farrokhi et al. (2022), ENVI-met is introduced as a three-dimensional modeling software used in environmental planning and design, analyzing variables such as air temperature, relative humidity, wind speed, and thermal comfort indices like PMV and PPD.

Parametric design tools such as Rhino and its Grasshopper plugin have also become extensively used for geometric modeling. For instance:

- In the study by Renjbarian, a three-dimensional parametric double-skin façade was modeled in Rhino and Grasshopper, followed by aerodynamic analysis using CFD. The results demonstrated the façade's superior performance in reducing wind pressure.
- Joharian (2018) used Fluent to study the effect of high-rise building arrangements in Isfahan on wind patterns, pressure, speed, and direction.

In summary, the integrated use of advanced simulation and modeling tools across multiple scales, micro (building), meso (urban block), and macro (neighborhood or city), enables more precise analysis and informed decision-making in climate-responsive urban design.

3.2 Selected Case Context

To investigate the impact of climate-responsive design, natural ventilation, and the role of wind flow in optimizing energy consumption in residential architecture, a comparative analysis was conducted across five Iranian cities: Bushehr, Hamedan, Tabriz, Tehran, and Isfahan. These cities, with their diverse climatic, topographical, and structural characteristics, provide a broad context for examining natural ventilation performance at various design scales.

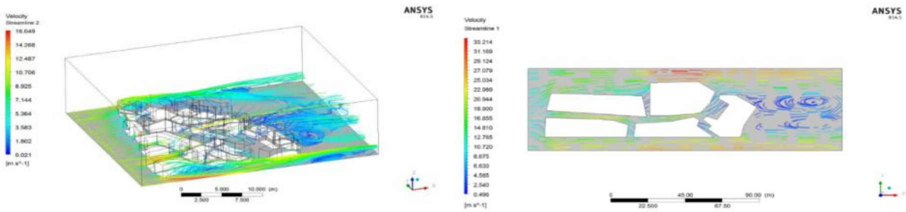

Figure 1: Establishing Bernoulli's law in a passage under fluid flow, based on changing the passage width (Mohajerani, 2014).

3.2.1 Bushehr (Hot and humid climate, Persian Gulf coast)

Bushehr, a coastal city in southern Iran, features a hot, humid, and windy climate. In this city, traditional urban fabric patterns such as narrow alleys, orientation of pathways relative to prevailing winds, and varied facade heights have evolved to utilize wind flow for natural cooling of spaces.

According to the study by Mohajerani (2014): The sea-facing orientation of alleys and their varying cross-sections result in channeling wind flow, increasing input pressure, and improving natural ventilation in interior spaces.

3.2.2 Hamedan (Cold and Windy Mountainous Climate)

Situated on the foothills of Mount Alvand with its cold mountainous climate, Hamedan experiences prolonged winters and intense wind currents. These distinctive conditions establish the city as an exemplary setting for assessing climate-responsive design strategies in high-rise residential constructions.

As documented in Karimimoshaver et al. (2023): Recessed balconies featuring three-sided enclosure, rectangular configuration, and southeastern orientation represent the predominant architectural form in Hamedan's high-rise structures. Furthermore, the study reveals for approximately 45% of the annual cycle, thermal comfort can be effectively maintained through natural ventilation alone, eliminating the necessity for mechanical cooling systems.

The results demonstrate that curved corner designs and building orientation can increase wind speed by up to 50% at certain points, while shaded areas are approximately 2.8°C cooler and 12% more humid than sun-exposed areas. Additionally, CFD simulations revealed a 10-50% deviation from field data in turbulent zones, highlighting the limitations of the standard k-ε model.

3.2.3 Tabriz (Cold Semi-Arid Climate with Strong Winds)

Tabriz, characterized by a cold semi-arid climate and strong winds, provides a suitable setting for analyzing double-skin façades and dynamic building forms in high-rise structures. According to Ranjbarian (2022) the parametric double-skin façade, designed and tested using CFD simulation in the cold climate of Tabriz, demonstrated improved performance in reducing wind pressure and regulating natural ventilation.

3.2.4 Tehran (A Megacity with High Pollution and Diverse Climate)

In Tehran, especially in densely populated neighborhoods such as Saadat Abad and Narmak, the main challenge in climate analysis is not only temperature but also air pollution and stagnation. According to Nouri et al. (2024), Increased building density and height disrupt urban wind flows and reduce the capacity for pollutant dispersion.

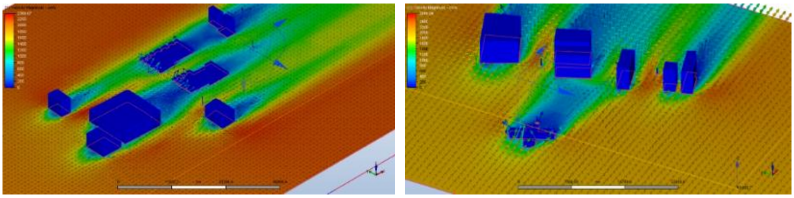

Figure 2: Wind speed simulation with vector representation at two different sites with different building heights and layouts (Nouri et al., 2024).

3.2.5 Isfahan (Semi-arid climate and regular geometric structure)

Isfahan, with its organized urban grid and dry climate, provides a suitable context for analyzing the impact of building block arrangements on wind flow. According to Joharian (2018), An impermeable layout behaves like a solid mass against wind flow, leading to air stagnation behind the blocks, whereas appropriate spacing helps reduce the wake of stagnant air.

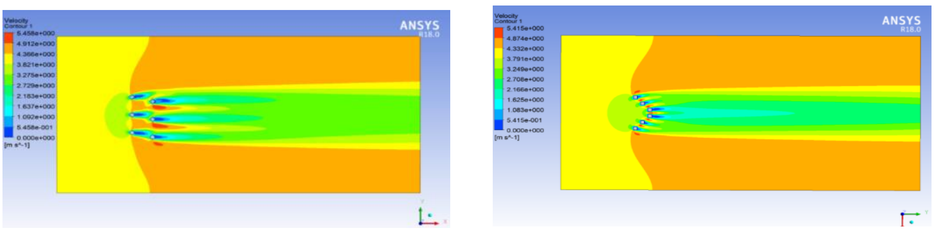

Figure 3: the layout and different distances of buildings in ANSYS software (Joharian ,2018)

In the research of Farrokhi et al. (2022), key climatic variables such as air temperature, relative humidity, wind speed, and thermal comfort indices (PMV and PPD) were comprehensively analyzed. This research, by considering the impact of urban form and building configuration on the microclimate, demonstrates that proper design of urban spaces can significantly improve residents' thermal comfort and reduce energy consumption in the building sector. The results of the numerical simulations in this study confirm the importance of aligning urban form with climatic conditions and provide more practical solutions for designing sustainable urban spaces in semi-arid regions.

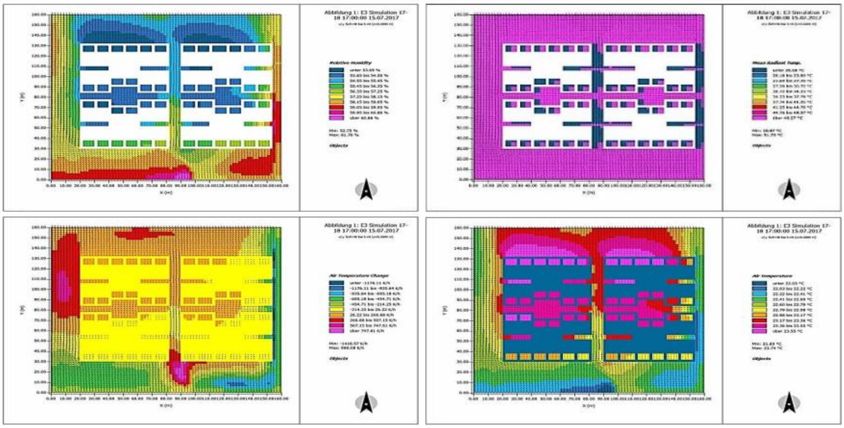

Figure 4: Thermal comfort simulation data in four patterns of spatial structure in 12 months of the year (Farrokhi et al., 2022).

The climatic and morphological diversity of these five cities enables a comparative analysis across warm-humid, cold mountainous, dry, dense, and polluted environments. The selection of these case studies allows the research to investigate climate-responsive design strategies and natural ventilation solutions within real and varied Iranian scenarios, and to derive applicable models for policymaking or architectural planning.

3.3 Key Findings: Wind Corridors, Building Layouts, Ventilation Potential

The analysis of simulation data and case studies in various Iranian cities identifies three main axes as key determinants in optimizing natural ventilation and reducing cooling loads: the creation of wind corridors at the urban scale, the optimization of building mass configurations, and the enhancement of natural ventilation potential through form and spatial organization.

3.3.1 Wind Corridors

Wind corridors are pathways within the urban fabric that enable the passage of airflow at micro and meso scales. Studies emphasize that the proper orientation of streets and passages relative to the prevailing wind, along with open spaces between buildings, increases ventilation and thermal comfort.

In a study by Mohajerani (2014) in Bushehr, it is stated the building should be open, outward-facing, and elongated to benefit fully from all air movement... The surface area to volume ratio should be higher to increase the airflow passing through.

3.3.2 Building Layouts

The arrangement of blocks and their spacing is one of the most important factors affecting the circulation and penetration of wind flow. In a study by Joharian (2018), based on 45 simulated models in Isfahan, the following results were reported that the greater the distance between blocks, the higher the airflow passing through the complex, and the smaller the stagnant zones created an impermeable layout acts like a solid body and prevents effective wind passage. It is also stated that the angle of building orientation relative to the wind direction, especially in the east-west and northwest-southeast directions, has a direct impact on the speed, pressure, and circulation pattern of airflow.

3.3.3 Key Research Findings:

- Designing open pathways aligned with the prevailing wind within the urban fabric is critically important, especially in hot and humid or windy climates.
- Increasing the spacing between buildings and selecting elongated forms with optimized orientation relative to the wind improves airflow and reduces negative pressure behind blocks.
- Natural ventilation varies across different spaces depending on location, time of day, building form, and facade openings, requiring precise design based on simulation.

4. IMPLICATIONS FOR ENERGY EFFICIENCY AND POLICY

Research findings indicate that harnessing natural ventilation and climate-responsive design is not only an effective strategy for reducing building energy consumption, but also carries significant implications for urban policy-making. Based on existing evidence:

- Urban design, as a qualitative intervention in creating sustainable urban places, must incorporate energy efficiency goals by responding to environmental contexts in the design of urban fabrics.
- Contrary to the common perception, energy efficiency is not achieved solely through interventions at the scale of individual buildings. Rather, at the intermediate scale, namely cities, urban areas, and neighborhoods—there is a strong relationship between form, design, and the spatial location of residential areas with energy consumption in housing and transport sectors.
- Key strategies for energy-efficient design include:

1. Reducing energy demand through building form, orientation, insulation, natural shading, and climate-conscious design
2. Optimizing energy use via intermediary spaces, natural ventilation, daylighting, and efficient single-sided ventilation
3. Utilizing renewable energy sources such as wind and solar in residential and façade design

- Climate-responsive design, particularly in dense urban areas, requires consideration of urban and morphological scales. In other words, the impact of urban design at the scale of block, mass/void configuration, and street network—as three fundamental components—can reduce energy consumption by up to fourfold.
- It is also emphasized that natural ventilation through façade design elements such as balconies, fin walls, and varied openings directly influences both thermal comfort and the energy consumption of cooling systems.

Ultimately, the evidence highlights that effective energy policy must go beyond macro-level or purely engineering approaches, and recognize the potential of design at the scale of urban fabric and buildings as a primary tool for energy optimization.

4.1 Microclimate-Aware Design as a Complementary Energy Strategy

Microclimate-based design is an approach that, instead of relying solely on generalized meteorological data or energy-intensive mechanical solutions, focuses on local climatic conditions within the near-surface layer of the environment. From this perspective, each site, street, or urban block possesses unique microclimatic characteristics that, when accurately analyzed, can inform strategies to reduce energy consumption and enhance thermal comfort. In the research of Farrokhi et al. (2022), it is stated the microclimate affects comfort conditions in both outdoor and indoor spaces. Small-scale strategies such as central courtyard design, natural shading, semi-open spaces (such as verandas, balconies, and open lobbies), and varied façade heights play a significant role in regulating the microclimate. In this context, it is noted that climate-responsive design is based on the integration of climate-adapted small blocks with adjacent buildings and open spaces, enabling the use of natural potentials such as ventilation, daylight, and solar heat gain during winter. Microclimate-aware strategies offer additional benefits in densely populated and compact urban environments, as they can reduce heating and cooling demands by managing local conditions such as wind, shading, humidity, and solar radiation.

In summary, microclimate-sensitive design not only complements energy-saving policies and technologies, but also represents a low-cost, ecologically adaptive approach grounded in local potential—an approach that is applicable even within existing residential fabrics.

4.2 Integration with National and Local Energy Policies

Research findings in the field of climate-responsive and energy-efficient urban design highlight that, in order to achieve long-term energy efficiency goals, integrating these approaches into national and local energy policies is essential.

Studies conducted in Iran reveal a significant gap between current energy policies and the requirements of climate-responsive urban design—particularly at the intermediate scale of urban fabric. This is a critical oversight, as many energy-efficient design strategies are most effectively implemented at this very scale.

Key recommendations for integrating climatic design into energy policymaking include:

- Revising national regulations and standards related to building energy efficiency to incorporate urban design indicators such as form, orientation, and mass/void configuration.

- Developing urban design guidelines tailored to the diverse climatic regions of the country, aiming to provide localized models for use in master and detailed plans.
- Strengthening urban climate components within planning processes, particularly in local policies related to housing development and new urban areas.
- Recognizing the importance of the intermediate scale in energy policymaking: Unlike the prevalent focus on national or micro (building-level) scales, it must be acknowledged that energy consumption at the city and neighborhood levels is directly related to urban design and form.

Ultimately, the success of energy policies in Iran depends on cross-sectoral collaboration among architects, urban planners, energy engineers, and policymakers. Only through such integrated efforts can energy-efficient, resilient, and climate-adaptive urban design be achieved at both national and local levels.

CONCLUSION AND POLICY RECOMMENDATIONS

The findings of this research demonstrate that urban form and climate-responsive design at the block and neighborhood scale have a significant impact on energy consumption, thermal comfort, and local microclimate quality. Based on simulation results and spatial analyses, the following conclusions can be drawn:

- Spatial layout, permeability, and orientation of buildings relative to prevailing winds play a key role in facilitating natural ventilation. Stepped, open, and semi-permeable urban forms have shown superior performance in terms of thermal comfort and energy use.
- In cold and windy climates such as Hamedan and Tabriz, applying localized design strategies—including enclosed balconies, multiple window openings, and fin walls—has reduced the need for mechanical cooling by more than 45%.
- In hot and humid regions like Bushehr, leveraging the prevailing wind direction in the design of streets, building forms, and spacing has significantly improved ventilation and reduced thermal loads.

Based on the research findings, the following are proposed as key policy recommendations to integrate climate-responsive design with urban energy planning:

1. Develop climate-based urban design regulations at micro and meso scales, focusing on block form, building orientation, and the design of open and semi-open spaces.
2. Establish an executive checklist to assess energy-efficient urban forms in residential and urban projects, including indicators such as built-to-open space ratio, surface-to-volume ratio, window-to-wall ratio, and dominant orientation.
3. Enhance cross-sectoral coordination between architecture, urban planning, energy, and environmental agencies to ensure climate-responsive approaches are reflected in national policies and spatial development frameworks.
4. Support interdisciplinary research and the use of advanced simulation tools such as CFD, ENVI-met, and DesignBuilder in urban design processes to enable data-informed decision-making.

Adopting a climate-responsive urban design approach alongside comprehensive national and local energy policies represents a crucial step toward sustainable development, improving urban quality of life, and reducing dependence on fossil fuels.

Summary of Key Insights

Natural ventilation and climate-responsive design can directly reduce cooling energy consumption in Iranian urban areas, especially when building form, massing layout, and window placement are aligned with prevailing wind directions. The diverse climatic zones of Iran (from Bushehr to Hamedan) offer significant potential for passive design strategies. Successful vernacular examples, such as narrow shaded alleys in Bushehr or semi-enclosed balconies in Hamedan, highlight the value of microclimate-sensitive design in urban planning. Urban form at the block and neighborhood scale has a greater influence on energy performance than individual buildings. Permeable layouts, optimized density, and well-balanced open and built spaces improve wind flow and enable natural ventilation. The use of analytical and simulation tools, including CFD, ENVI-met, and Space Syntax, plays a vital role in designing and evaluating climate-adaptive forms, particularly for analyzing microclimate and airflow in dense urban settings. Major barriers to implementing climate-responsive design include the lack of coordinating institutions, the dominance of technocentric policies (focused on the building scale), regulatory gaps, and limited professional education. These must be addressed through policy reform, development of localized urban codes, and promotion of vernacular design principles. Integrating climate-responsive design with national and local energy policies is essential. Reforming urban and building regulations to reflect climatic indicators—and placing greater emphasis on the meso scale (block and neighborhood), can yield more effective outcomes. Microclimate must be considered a key layer in urban design analysis. A microclimate-aware approach complements energy policies at both the building and urban scales, especially through the spatial organization of built form and open space.

Strategic Recommendations for Urban Planners and Energy Policymakers

1. **Integration of Climate-Responsive Principles into Master and Detailed Urban Plans:** Urban design must align with regional climatic characteristics. Indicators such as microclimate conditions, solar radiation, natural ventilation, and wind flow should be explicitly embedded in urban development regulations.
2. **Development of a Strategic Framework for Sustainable Urban Form**

This framework should be structured around three pillars:

- Software-based actions: education, policy development
- Hardware-based actions: reform of construction codes
- Mindware-based actions: public awareness and specialized research

3. **Enhancing Climate-Based Design Based on Natural and Vernacular Contexts:** Adoption of compact forms, uniformly oriented plots, and optimized building depth (10–14 meters) is recommended to utilize solar energy, daylighting, and natural ventilation effectively.
4. **Utilization of Advanced Analytical Tools in Urban Decision-Making:** Tools such as CFD, ENVI-met, and climate modeling software can

support data-driven analysis and climate-sensitive design at the block and neighborhood scales.

5. **Development of Localized Climate Design Guidelines for Diverse Urban Contexts:** Based on Iran's diverse climatic zones, practical and localized guidelines for urban spaces and buildings should be prepared, suitable for use by municipalities and design offices.
6. **Support for Regeneration of Existing Urban Fabrics and Brownfield Redevelopment:** Tapping into urban regeneration opportunities can improve energy performance, especially in deprived or deteriorated neighborhoods, and should be considered a strategic implementation path.
7. **Cross-Sectoral Coordination among Architecture, Energy, Environment, and Planning Sectors:** Achieving climate-adaptive and energy-efficient urban design requires sustained collaboration among governmental bodies, academic institutions, and professional organizations.

Suggestions for Future Research

It is recommended that future studies pilot various urban form typologies in major Iranian cities across different climatic regions (such as hot-arid, temperate, and cold mountainous climates). The goal is to develop climate-responsive urban form design guidelines tailored to each climatic context.

1- Emphasizing Urban Climate in Master and Detailed Plans Microclimatic factors must be given greater consideration in urban development plans. Their impacts on block morphology, street network design, and mass–void patterns should be thoroughly investigated.

2- Identifying Spatial–Morphological Factors Influencing Energy Use and Thermal Comfort: Given the diversity of urban environments in Iran, it is essential to analyze the form-related variables of building clusters and open spaces specific to each climate zone in order to provide context-sensitive design strategies.

3- Integrating Key Microclimatic Variables: Vegetation, Solar Radiation, Shading, and Humidity: Building on previous studies such as the Valley Street project, future work should analyze the individual and combined effects of vegetation, shading, humidity, and radiation to extract optimal values for urban climate-sensitive planning.

4- Reevaluating National Building Codes with an Urban Energy Perspective: It is proposed that existing codes be revised to include not only individual building features but also urban fabric characteristics and form-related components.
5- Combining Numerical Modeling and Field Analysis in Future Research Simultaneous use of CFD, ENVI-met, and DesignBuilder software alongside field measurements is recommended to improve the accuracy, realism, and practical applicability of research findings.

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CHAPTER 4
CHINA'S OIL DIPLOMACY IN SOUTH SUDAN: CONFLICT, CONTESTATION OR COOPERATION

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INTRODUCTION

Oil remained a very critical tool of diplomacy in the drive for sustainable energy by states. This has intensified global competition for energy resources thereby shaping the geopolitical strategies and economic priorities of state actors such as China (Wang, Ren, & Li, 2024). China has deepened its engagement in Africa's oil sector, being the world's second-largest oil consumer. South Sudan became an important state with Chinese oil interest since its independence in 2011. The China National Petroleum Corporation (CNPC) control approximately 75% of South Sudan's oil production, which positioned China as a dominant player in the sector (Jureńczyk, 2021). The unstable socio-political and security environment in South Sudan continued to impede China's quest for energy security.

The China's oil diplomacy is analysed by looking at oil conflict, contestation over oil resources and cooperation between China and other regional actors to entrench peace and stability. Therefore, China's involvement in the oil sector of South Sudan reflects a complex interplay of strategic interests and local dynamics. The conflict dimension is seen in the disruptions caused by South Sudan's civil war, in 2013 and frequent outbreak of violence by rival groups which result in the attacks on oil infrastructure. This exposed the vulnerabilities of China's investments and the fragility of the oil-dependent economy of South Sudan. (Etyang & Panyako, 20202). Contestation arises from disputes over oil revenue sharing between Sudan and South Sudan, with China mediation to securing access to pipeline, as well as from Western critiques accused China of complacency in corruption and autocratic governance under President Salva Kiir (Schlein, 2024). Conversely, cooperation is construed in terms of China's diplomatic efforts to secure its investments and citizens through economic aid, security partnerships, and peacebuilding initiatives (Aulia, 2021).

This chapter argues that China's oil diplomacy swing across conflict, contestation, and cooperation, while acknowledging South Sudan's sovereignty in the pursuit of its global energy strategy within the regional security and geopolitical dynamics.

1. BACKGROUND TO CHINA'S OIL DIPLOMACY IN SOUTH SUDAN

To achieve its economic and geopolitical goals, energy security is at the center of China's broader development agenda. As one of the world's largest oil importers, its oil consumption is projected to reach about 15 million barrels per day by 2030 (Russell, 2025). Faced by the need for energy to bolter domestic production, China has increasingly turned to Africa as a means of diversifying its energy supply and reduce reliance on Middle Eastern oil because of conflict which disrupt oil shipment (Garlick & Havlová, 2020). The oil-rich nations of Africa, particularly those with natural resources and less rivalry with foreign interests, have become very strategic priorities for Beijing. South Sudan commands an estimated 3.5 billion barrels in its oil reserves making a critical stakeholder in international oil markets (Ponnie, 2025). China sees great potentials in investing in South Sudan oil sector as broader strategy for energy security goals while advancing its Belt and Road Initiative (BRI) to promote economic and diplomatic ties with other states (Jureńczyk, 2021). Hence, this puts South Sudan as one of China's strategic partner its global energy quests.

Since South Sudan gained its independence in 2011, the oil sector has been relied on, approximately 90% of government revenue and 98% of export earnings is accrued through oil. The oil production from the unity states and the upper Nile reached a peak of 350,000 barrels per day before the civil war. However, this has since fluctuated due to conflict and dispute with Sudan over pipeline revenue sharing. As at the first quarter of 2025, South Sudan oil production is estimated at about 90,000 barrels per day which amount to a deficit of 260,000 barrels (Agency Ecofin, 2025). The overreliance on oil and dwindling oil revenues weaken the state economic and social development. The oil industry stakes in South Sudan is largely control by the Greater Nile Petroleum Operating Company under which the China National Petroleum Corporation (CNPC) operates. The CNPC invested in upstream exploration, infrastructure development, production which underscore the strategic role of China in shaping the oil-dependent economy of South Sudan. Despite China's dominance in the oil sector in South Sudan, the sector is vulnerable to incessant violence, political instability and regional disputes, which has threatened both the production and China's energy security objectives. Additionally, the dispute between Sudan and South Sudan over sharing the oil resources and the disputed oil rich region of Abyei has continued to threaten oil production (Patey, 2017). For instance, this division has led to a prolonged conflict over oil revenue sharing and its access to Sudan's pipeline infrastructure, critical for exporting South Sudan's landlocked oil. China, which has been a long-standing partner of Sudan's in the oil industry since the 1990s, adeptly navigated the secession by maintaining relations with both nations. In Pre-independence era, China invested heavily in the oil sector of Sudan, constructing pipelines and refineries through CNPC. Post-2011, the focus of Beijing was shifted to South Sudan, leveraging its established expertise to secure contracts and expansion of oil operations. The transition was complicated and fraught with quite difficulties for China to navigate the tension of Sudan-South Sudan to securing access to the pipeline, while adjusting to the unstable politics and security situation of South Sudan. Therefore, China's oil diplomacy in South Sudan and the Horn of African is influenced by the historical dynamics and geopolitical challenges (Belmadi & Kadri, 2024).

1.1 Navigating Conflict, Security Risks and State Fragility in South Sudan

Since December 2013, when the political and ethnic tensions broke out between President Salva Kiir and former Vice President Riek Machar, leading to civil war in South Sudan, the oil sector has been severely disrupted, which supports both its economy and China's energy interests (Patey, 2017).

Militant factions, particularly with those aligned with Machar, targeted oil infrastructure in the Upper Nile and Unity States, where the China National Petroleum Corporation (CNPC) operates, thereby disrupting oil production and foreign exchange earnings from the export of oil. In early 2014, for example, rebel forces attacked the oil facilities in Bentiu, damaging the critical wells and pipelines which linked the Greater Nile Petroleum Operating Company. This led to the oil production drop from 245,000 barrels per day in 2013 to below 100,000 by mid-2014, compelling the CNPC to remove personnel and temporary cease activities in the affected areas (James, 2015). With an estimated 60% loss of its oil revenue, South Sudan suffered worsening fiscal deficits and obstruction of the development efforts which significantly resulted in the economic fallout.

The Revitalized Agreement on the Resolution of the Conflict in South Sudan was a major milestone achieved by regional actors in 2018 after the civil war. The agreement was aimed at restoring peace and to address ethnic divisions, widespread violence and humanitarian emergencies arising from the violent conflict. Furthermore, the agreement stipulated the establishment of a transition government through power-sharing arrangement and an eventual election. Since the agreement was signed, the conflict has continued to rage leading to the collapse of the transition government peace and the inability of Kiir government to organize the elections as recommended by the agreement (Darboe, 2022).

The conflict continued to frustrate the economy of South Sudan especially the oil sector which contribute the huge share of its foreign exchange. The $5 billion Chinese investments in the oil sector of South Sudan continued to face persistent security risks due to the country's unpredictable security atmosphere (Ali & Mohamed, 2023). Conversely, Chinese personnel and infrastructure in South Sudan and CNPC-operated oil fields and pipelines remained vulnerable in those conflict areas. For instance, in 2014 the CNPC pulled out hundreds of workers from the Unity State following rebel threats. This underscore the direct threats to personnel safety. To reduce these risks, China went further in engaging private security firms and coordinated with South Sudanese forces thereby increasing the costs of production and straining bilateral relations (Jureńczyk, 2021).

China's energy security is significant on the broader implications, China's oil imports from as South Sudan is small but resonate with the Beijing's strategy to diversify from Middle Eastern suppliers because of possibility for disruption arising from major security upset in the volatile region. However, the disruptions in South Sudan further threatened China's energy security goals of diversification. Although Beijing maintained its traditional policy of non-interference, it committed to contributing troops to the United Nations Mission in South Sudan, since 2015 (UNMISS), and marking a shift toward its active security engagement to protect its economic interests (Fung, 2022). These challenges have illustrated the delicate balance, that China must maintain between safeguarding its investments and navigating the unstable landscape of South Sudan.

The economy of South Sudan is particularly susceptible to internal conflict. Its heavy dependence on oil, which has generated around 90% of government revenue and 98% of export earnings. The incessant violence has disrupted the economy and worsened the state exercise of power to govern, exacerbating state fragility. Thus, China's oil diplomacy is focused on deescalating, national reconciliation and stabilizing South Sudan to enhance its oil investment. This undermined effective management of the oil resources resulting in corruption and ethnic divisions, weak governance, public discontent and the perpetuation of instability (Global Witness, 2023). For example, reports indicated that oil revenues have been poorly managed or diverted, with little benefit to local communities, which has contributed to the social unrest near oil fields. This violent disruption has created an unpredictable business environment for oil operations for China, as production halts and revenue disputes interrupt the investment returns. Furthermore, the South Sudan's economic instability strains relations with Sudan, which depends on transit fees for South Sudanese oil exports via its pipelines. Furthermore, this threatens the regional stability in the Horn of Africa (Crisis Group, 2024). The oil diplomacy of China which requires a stable operating environment, is thus undermined by South Sudan's systemic weaknesses, forcing Beijing in navigate a complex web of local and the regional dynamics to sustaining its energy interests.

2. CONTESTATION: GEOPOLITICAL AND LOCAL TENSIONS

Beyond the internal conflict dynamics in South Sudan, the disputes over the sharing of oil revenue and the access to Sudan's pipeline have become a source of contestation, complicating China's oil diplomacy in the region, both states have had disagreements over transit fees and the revenue allocation which resulted in the suspension of oil production and export. The disagreements over Sudan's demand for $36 per barrel in transit fees, severely impacting both Sudan and South Sudan's economies. As a primary stakeholder in South Sudan's oil sector, China through the China National Petroleum Corporation

(CNPC), has played critical role in mediation to ensure access to oil flow through Sudan's pipelines. China's peaceful development efforts tries to tame conflicts in South Sudan to ensure it oil investments and citizens are safe. China has tried to mediate between Sudan and South Sudan over dispute on payment of pipeline fee for oil export. The resumption of oil production would later be shut down for the same reason in 2023 within threatening to shut down the pipeline again except South Sudan complies. China was compelled to deploy its oil diplomacy to guarantee production and stability (Bodetti, 2019). Hence these disputes have not only disrupted China's access to South Sudanese oil but has also underscored the geopolitical complexities of managing relations with two interdependent yet adversarial states.

Additionally, the dominant role of China in South Sudan oil sector has drawn Western criticism, particularly, for allegedly enabling corruption and human rights abuses under the government of President Salva Kiir. Thus, oil revenues, which has been accounted for 90% of South Sudan's government income, have been poorly managed or diverted to fund patronage networks, and exacerbating governance failures (Global Witness, 2023). The Western governments and organizations, such as the United States and the European Union, have accused China of prioritizing its economic interests over the accountability, further arguing that its non-interference policy indirectly supports Kiir's autocratic regime (Crisis Group, 2017). This criticism have been amplified by the geopolitical rivals to curb the rapid growing influence of China in South Sudan which challenges Western dominance in African resource markets. For example, concerns have been raised and expressed by the U.S. has over China's Belt and Road Initiative (BRI) which is seen as expanding the Beijing's strategic foothold in the Horn of Africa, also potentially sidelining the initiatives of the Western-led development (Sacks, 2023). These tensions have underscored the contestation over the involvement of China, in positioning South Sudan as a battleground for competing global powers.

Another dimension of the contestation is the local discontent, which is driven by concerns over environmental degradation and livelihood disruptions because of Chinese oil operations (Global Witness, 2023). Communities in Upper Nile and Unity States have reported water contamination and displacement due to the activities of CNPC, with minimal compensation or local benefits in oil-producing regions. For instance, the protest in Melut County disrupted the oil operations in a 2020 community, and demanding environmental remediation and job opportunities. These grievances have sparked social unrest, with some communities accusing Chinese firms of collaborating with the government to prioritize oil revenues over local welfare (Chuot, n.d.). Therefore, this local contestation has undermined the Chinese energy security goals and forced its oil diplomacy towards people-focused diplomacy. This has often complicated the oil operations which highlight the needs for socially responsible investment practices to mitigating such domestic contestation over China's oil interest in South Sudan.

2.1 Cooperation, Diplomacy and Stabilization Efforts

To stabilize South Sudan, China has been engaged in a strong peace diplomatic effort to safeguard its oil investments, marking a shift from its traditional non-interference policy. High-level engagements have played a key role, with the officials of Chinese, including Foreign Minister Wang Yi, in 2019 and 2023, visiting Juba to renew security commitments and strengthened the bilateral ties (Crisis Group, 2017). These visits paved way for the stronger ties to improve and strengthen the protection of oil infrastructure operated by the China National Petroleum Corporation (CNPC) and support the government of South Sudan in maintaining stability (Jureńczyk, 2021). China played a major role in peacebuilding through its support for the 2018 R-ARCSS agreement. In 2020, China's mediation effort facilitated negotiations between South Sudanese warring factions in Beijing and called for the implementation of ceasefire and political reconciliation. These efforts China's oil diplomacy underscore its strategic interests for stable oil operations in South Sudan (Fung, 2022).

The economic and humanitarian support of China for South Sudan has been demonstrated bilateral trade milestones. China has provided substantial economic aid, beyond trade, including $150 million in grants and loans for infrastructure projects like roads and power plants in oil-producing regions. Additionally, China further provided humanitarian assistance, by delivering food aid and medical supplies to conflict-affected areas in communities, since 2019, with over $50 million allocated through the United Nations since 2019 (World Food Programme, 2019). Such support has underscored the commitments of China by stabilizing South Sudan, aligning with its economic interests with broader development goals. The security cooperation of China in South Sudan, has focused on the protection of its oil infrastructure while contributing to the regional stability (Patey, 2017). Hence since 2015, China has deployed over 1,000 troops to the United Nations Mission in South Sudan (UNMISS), with a mandate to securing very strategic areas, including the oil fields in Upper Nile State (Yin, 2022). This has marked a very significant departure from China's historical reluctance to engage in overseas security operations. Additionally, the trainings and equipment's to South Sudanese security forces to enhance their capacity to protect CNPC-operated facilities, was also provided by China through $20 million in military aid reported in 2020. More so, these efforts have balanced China's economic interests with regional stability goals, as to secure South Sudan to ensuring an uninterrupted oil exports and has strengthened China's influence in the Horn of Africa (Liu, 2023). However, China's involvement of security has sparked debates about its neutrality, given its economic stakes, and further highlighting the delicate interplay between cooperation and its strategic ambition.

2.2 China's Oil Diplomacy and Geopolitical Implications

China's dominance in the South Sudan oil sector through the China National Petroleum Corporation (CNPC) continued to shape geopolitics and domestic politics in South Sudan (Crisis Group, 2017). While the operations of CNPC provides the critical fiscal support South Sudan needs in the oil sector, it however, limit the policy independence of South Sudan and its geopolitical maneuver, as the government is constraint by the need to align with Beijing's interests to guarantee oil revenue flows (Jureńczyk, 2021). For instance, the South Sudan's acquiescence to Chinese-mediated oil agreements with Sudan has reflected a constrained on its sovereignty, thus as Juba prioritizes its economic survival over independent decision-making. Chinese investments in infrastructure grants have spurred development but further deepened dependency, with South Sudan owing its significant loans to China under opaque terms. This dependency risks entrenching a client-state dynamic, where the political autonomy of South Sudan is being subordinated to China's economic leverage and has raised concerns about long-term sovereignty (Liu, 2023).

One of the components of China's grand strategy is aimed at achieving its energy security. Thus, South Sudan oil sector is within its broader energy agenda. The strategy seeks to diversify oil supplies and to secure long-term energy supply. China views South Sudan's untapped reserves imperative to reducing its over reliance on volatile Middle Eastern markets (Patey, 2017). The 3.5 billion barrels of proven reserves positioned South Sudan as a strategic asset in in China's strategy energy security goals. Thus, the CNPC's operations aligned with China's Belt and Road Initiative (BRI) which seeks to integrate energy and infrastructure development.

China made investments in the regional connectivity projects the BRI such as roads, rails and bridges to link South Sudan's oil fields to export routes to enhance its control over the oil supply chains. This strategy aligns and strengthens the global energy security of China, through access to South Sudanese oil. However, it has also exposed Beijing to the risk and challenges that comes with South Sudan's instability. This necessitates diplomatic and security engagements with regional actors such as the AU and IGAD (Back, 2025). Thus South Sudan has exemplified China's broader approach of combining economic investment with geopolitical influence in securing the energy resources in Africa. China's oil diplomacy in South Sudan has significant ripple its effects on regional stability in the Horn of Africa, also influencing relations between Sudan, South Sudan, and neighboring states like Kenya and Ethiopia.

The disputes over the ongoing oil revenue in Sudan-South Sudan, and the mediation of China to securing the pipeline access underscores the interconnectedness of the region's economies (France-Presse, 2024). While the involvement of China's mediation has supported the temporary agreements, such as the 2013 deal to resume oil exports, the unresolved tensions risk the escalation bilateral conflicts, and potentially destabilizing the region (International Crisis Group, 2020). Conversely, the investments in infrastructure and peacekeeping in China, including its contributions to the United Nations Mission in South Sudan (UNMISS), also in fostering cooperation by promoting economic development and security. However, the growing influence of China has sparked great concerns among the regional actors about dependency and geopolitical imbalances, particularly as Beijing's BRI projects which extends to neighboring states in the region. China's ability to leverage its economic and diplomatic clout to support regional integration, lies in its potential to drive cooperation, but the risk of escalating tensions which will persists if local grievances and interstate rivalries are not properly addressed.

3. POLICY RECOMMENDATIONS

The South Sudan 90% over reliance on oil revenues has created economic vulnerability, political instability and conflict. This causes the urgent need to diversify the economy into non-oil sectors such as agriculture. The Investment in agriculture, utilization of Chinese skills and knowledge in irrigation and training, and the development of renewable energy sources like solar and hydropower with international supports can led to the reduction of oil dependency, jobs creation, and enhancement of economic resilience.

Addressing oil related corruption and accountability is imperative to attain stability and development in South Sudan. Therefore, the establishment anti-corruption institutions would help to entrench fight corruption and misappropriation of oil resource. These international actors such as the UN, IGAD and AU should continue to foster collaborative frameworks to mitigate conflict and to promote sustainable oil development. Collective effect by powerful states to stir South Sudan back to stability will be necessary. The western powers should engage Beijing constructively, co-financing infrastructure projects and encouraging its participation in regional security dialogues, rather than viewing the influence of China as a threat. This approach would align the energy goals of China, with its regional stability, fostering equitable development and the reduction of tensions in the Horn of Africa.

For China, the protection of its oil investment requires an improved security measure, such as the deployment of advanced surveillance at facilities operated by the China National Petroleum Corporation and the training of local forces, while adhering to the standards of human rights. The promotion of transparency through public environmental assessments and community benefit agreements can counter local and Western criticisms, thereby, enhancing the reputation of China as a responsible stakeholder in South Sudan’s oil sector. Additionally, the balance of these efforts must be accompanied with accountability. China’s mediation in Sudan and South Sudan oil disputes while maintaining neutrality will stabilize oil flows and revenues for both countries and maintain regional stability.

CONCLUSION

China is navigating a terrain of conflict, contestation and the need for cooperation at national and international levels to achieve its energy security goals in South Sudan. China’s oil diplomacy is shaped by the volatile security challenges in South Sudan which disrupts its oil infrastructure and compromises the safety of its citizens and the flow of the oil to meet its energy demands. Thus, China's oil diplomacy represents an interplay of its BRI strategy and the complex geopolitical dynamics in the race for energy security particularly in the oil sector of South Sudan. As the second largest consumer of oil, China is compelled to ensure an undisrupted oil supply chain. Also, it tries to diversify oil supply to avoid disruption due the volatile security in the Middle East. As a dominant play in the in South Sudan, the CNPC controls 75% of the oil production.

Despite China's dominant role in South Sudan’s oil sector, it suffers huge challenges such as persistent violent conflicts, regional rivalries and divergent interests of international actors. China faces three-dimensional challenges in terms of conflict, contestation and cooperation. Since 2013 South Sudan has experienced civil war and persistent violent conflict. The conflict has continued to destroy critical infrastructure including oil installations and pipelines which saw production drop from 350,000 in 2013 to 90,000 barrels per day by 2025. This incessant destruction of oil infrastructure puts China’s investment, and personnel in jeopardy and further exacerbate the volatility of South Sudan's economy that is over 90^ dependent on oil. China continued to navigate the complex violent ecosystem and pursue lasting peace not only in South Sudan but across the region. Contestation also emerged between Sudan and South Sudan with China sandwiched between them over the sharing of oil revenue. China continued to mediate between the two countries to ensure the safe passage of oil for export. Another contested issue is the accusation that China continued to indulge despotic leaders and perpetuate corruption such as the Trinity oil saga in which President Salva Kiir is believed to have been involved. Domestic grievances are also targeted at China by local communities for environmental pollution negligence and lack of corporate social responsibility projects by the CNPC which adds another layer to the complex contestation.

Despite these challenges, China continued to invest in South Sudan’s oil sector, provided economic aid and supported the peace process through IGAD, and AU and the contribution of military personnel for peacekeeping to ensure the stability of South Sudan. China has mediated between Sudan and South Sudan, provided troops for the UN peacekeeping deployment tagged United Nations Mission in South Sudan (UNMISS) and contributed $150 million as economic aid and another $50 million for humanitarian interventions. China's peace diplomacy has seen a significant shift from its policy of non-interference in the domestic affairs of states to peacebuilding and quest for regional stability. This aligns with the strategic goals of the BRI.

China’s commitment to oil investments, foreign aid and mediation has been seen as an infringement on sovereignty, undermining its political autonomy and causing economic dependency. The dynamics in South Sudan is a miniature of strategic expansion in Africa to drive its energy security goals and show how China maneuver between meeting its energy security ambitions and threading the complex geopolitical landscape through oil diplomacy. Therefore, the domestic politics and geopolitics on global energy competition influence China’s oil diplomacy in South Sudan.

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CHAPTER5
ENERGY STRATEGIES OF MAJOR GLOBAL ACTORS: CHINA, THE US, THE EU, ETC.

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INTRODUCTION

In recent decades, energy has increasingly been recognized not merely as a commodity or an economic input, but as a critical pillar underpinning national security, international relations, and sustainable development [1]. The global energy landscape is undergoing a period of rapid and complex transformation, driven by growing concerns over energy security, environmental degradation, and climate change, alongside the evolving dynamics of global power structures [2]. Nations are now compelled to reconsider their energy strategies, balancing between securing affordable, reliable energy supplies and transitioning to low-carbon, sustainable energy systems [3].

Historically, the control and distribution of energy resources have played a decisive role in shaping the geopolitical order [4]. From the oil crises of the 1970s to the current debates over natural gas supplies in Europe, energy has consistently influenced diplomatic relations, economic competitiveness, and military strategy [5]. In today's interconnected world, these dynamics are becoming even more pronounced as nations grapple with volatile energy markets, the accelerating impacts of climate change, and the urgent need to decarbonize their economies in line with international climate agreements such as the Paris Accord.

Among the world's major global actors, China, the United States, and the European Union occupy particularly influential positions in determining the direction of global energy trends. Collectively, these actors account for a significant share of global energy consumption, production, and greenhouse gas emissions. Their policy choices and strategic decisions have implications that extend far beyond their borders, influencing global commodity prices, investment flows, technological innovation, and international regulatory frameworks. Understanding their evolving energy strategies is therefore crucial for anyone seeking to comprehend the future of global energy governance and the broader geopolitical implications of the energy transition (Fig 1).

Fig1. Global Energy Strategies

The Nexus of Energy Security, Climate Change, and Geopolitics

At the heart of modern energy policy lies a delicate balance between three interrelated and sometimes conflicting objectives: ensuring energy security, mitigating climate change, and managing geopolitical interests [6]. Energy security, broadly understood as the uninterrupted availability of energy at affordable prices, remains a primary concern for policymakers. It involves reducing dependence on foreign energy supplies, diversifying energy sources, and securing critical infrastructure against potential disruptions.

Simultaneously, the accelerating pace of climate change has made the transition to low-carbon energy systems an urgent global priority [3]. Rising global temperatures, increasing frequency of extreme weather events, and mounting scientific evidence linking greenhouse gas emissions to environmental degradation have placed unprecedented pressure on governments to reduce their carbon footprints. This shift entails not only transitioning from fossil fuels to renewable energy sources but also rethinking energy consumption patterns, investing in energy efficiency, and promoting sustainable technological innovations [7].

Adding a further layer of complexity is the geopolitical dimension of energy policy [8]. Control over energy resources, supply routes, and critical technologies confers significant strategic advantages on nations and can be a source of both cooperation and conflict. Recent events — such as the geopolitical tensions surrounding energy flows in Eastern Europe, disputes over maritime resources in the South China Sea, and competition over leadership in emerging technologies like green hydrogen — illustrate the continuing relevance of energy as a tool of geopolitical influence.

For global powers like China, the United States, and the European Union, navigating this nexus of energy security, climate change, and geopolitics is a formidable challenge. Their respective energy strategies reflect not only domestic priorities but also broader geopolitical ambitions and environmental commitments [9]. While there are areas of convergence, such as shared investments in renewable energy and emissions reduction targets, significant divergences remain in their approaches to fossil fuel dependency, energy diplomacy, and international energy governance [10].

Objectives and Scope of the Chapter

This chapter aims to examine and compare the contemporary energy strategies of three of the world's most influential global actors: China, the United States, and the European Union. By analyzing their policy priorities, regulatory instruments, and international engagements, the chapter seeks to uncover the underlying drivers, similarities, and differences shaping their respective energy transitions.

The core objectives of the chapter are as follows:

1. **To provide an overview of the evolving global energy landscape**, highlighting key trends, challenges, and opportunities influencing national and international energy strategies [11].
2. **To examine the energy strategies of China, the United States, and the European Union**, with a particular focus on their strategic priorities, policy instruments, and approaches to renewable energy deployment, fossil fuel dependency, and energy security [12].
3. **To analyze the role of energy diplomacy and geopolitics** in shaping these actors' energy strategies and their positions within international energy governance frameworks [13].

4. **To identify areas of convergence and divergence** among these actors, offering insights into the potential for cooperation or conflict in the global energy transition [14].
5. **To contribute to the broader academic and policy discourse** on global energy governance by providing a comparative, evidence-based analysis of major global actors' energy policies [15].

While the primary focus will be on China, the United States, and the European Union, the chapter will also briefly reference other significant players and regional contexts where relevant, to situate the analysis within the broader global energy environment.

Methodology and Comparative Analytical Approach

To achieve these objectives, the chapter employs a comparative analytical approach, combining qualitative policy analysis with the examination of empirical data from reputable international sources. The methodology involves several interrelated components:

First, a review of existing literature on global energy policy, geopolitics, and climate change mitigation will provide a theoretical and contextual foundation for the analysis. Academic articles, policy papers, government documents, and reports from international organizations such as the International Energy Agency (IEA) [16], the International Renewable Energy Agency (IRENA), and the United Nations Framework Convention on Climate Change (UNFCCC) will be consulted to establish a comprehensive understanding of current debates and developments [17].

Second, the chapter will conduct an in-depth analysis of national and regional energy strategies. This includes examining official policy documents, strategic plans, regulatory frameworks, and public statements from government officials and institutions in China, the United States, and the European Union. Particular attention will be paid to the most recent policy announcements, climate targets, and energy investment patterns to capture the current state and future direction of each actor's energy policy [18].

Third, the chapter will incorporate a geopolitical analysis, assessing how energy strategies intersect with broader foreign policy objectives, international partnerships, and regional security concerns [19]. This involves analyzing diplomatic initiatives, international energy cooperation agreements, and major energy infrastructure projects with cross-border implications.

Finally, through comparative analysis, the chapter will identify areas of alignment and divergence in the energy strategies of the three actors, exploring the implications for global energy governance and the prospects for multilateral cooperation in addressing shared energy and climate challenges.

By combining policy analysis, empirical data, and geopolitical insights within a comparative framework, this chapter aims to provide a nuanced, multidimensional understanding of how the world's major global actors are navigating the complex, interrelated challenges of energy security, climate change, and geopolitics in the 21st century.

1. GLOBAL ENERGY LANDSCAPE OVERVIEW

1.1 Current Trends in Global Energy Demand and Supply

The global energy landscape has undergone significant transformation in recent decades, driven by rapid economic development, technological innovation, and heightened environmental awareness [20]. As of the mid-2020s, global energy demand continues to rise, particularly in emerging economies, while developed nations pursue policies aimed at stabilizing or even reducing consumption through efficiency improvements and decarbonization initiatives. According to the International Energy Agency (IEA, 2024), global primary energy demand increased by approximately 2.1% in 2023, a modest rise compared to previous years, reflecting a post-pandemic economic recovery and the growing energy needs of industrializing nations in Asia and Africa.

Notably, energy demand growth remains unevenly distributed across regions. While countries such as India, China, and several Southeast Asian nations experience robust increases in consumption, many European states and North America have seen relatively stable or declining demand, largely as a result of energy efficiency gains, demographic trends, and structural shifts in their economies towards less energy-intensive service sectors. For example, Germany's total primary energy consumption declined by 4.7% in 2023, driven by reduced industrial output, high energy prices, and an accelerated shift to renewables.

On the supply side, the global energy mix continues to be dominated by fossil fuels, although their share is gradually declining in favor of renewable sources. In 2023, fossil fuels — comprising oil, natural gas, and coal — accounted for approximately 77% of total primary energy consumption worldwide (IEA, 2024). However, the growth rate of renewables has consistently outpaced that of fossil fuels over the past decade. Solar photovoltaic (PV) and wind power in particular have expanded rapidly, with global solar capacity increasing by nearly 24% and wind power by 13% in 2023 alone. Hydropower remains the largest source of renewable electricity, although its growth has slowed due to environmental concerns and limited suitable sites for new large-scale projects.

The global liquefied natural gas (LNG) market has also experienced significant growth, driven by increasing demand in Asia and efforts by European countries to diversify away from pipeline gas imports, especially from Russia, following the geopolitical tensions surrounding the invasion of Ukraine. This shift has had notable implications for global energy security, price volatility, and infrastructure development [21].

1.2 The Role of Fossil Fuels vs. Renewables Globally

Despite substantial progress in the deployment of renewable energy technologies, fossil fuels continue to play a dominant role in meeting the world's energy needs [2]. Oil remains the largest single source of primary energy, accounting for roughly 29% of global consumption in 2023, followed by coal at 26% and natural gas at 22% (IEA, 2024). The resilience of fossil fuels in the global energy mix can be attributed to their high energy density, established infrastructure, and critical role in sectors where decarbonization remains challenging, such as heavy industry, aviation, and maritime transport.

Coal, in particular, has shown unexpected resilience in recent years, especially in Asia. While coal consumption has declined sharply in Europe and North America due to environmental regulations and carbon pricing mechanisms, countries such as China and India have continued to rely heavily on coal to support their growing electricity demand and industrial output. In

2023, China alone accounted for over 50% of global coal consumption, driven by both new coal-fired power plant capacity and the need to stabilize grid operations amid fluctuating renewable generation.

Conversely, the role of renewables in the global energy system has expanded rapidly, supported by falling costs, supportive policy frameworks, and increasing investor interest. The levelized cost of electricity (LCOE) for solar PV and onshore wind has fallen by more than 85% and 70%, respectively, since 2010, making them cost-competitive or even cheaper than new fossil fuel capacity in many markets. In 2023, renewables accounted for nearly 30% of global electricity generation, a record high, with particularly strong growth in China, the United States, and the European Union [22].

However, the integration of variable renewable energy sources presents significant challenges for grid stability, system flexibility, and storage capacity. Addressing these issues requires the deployment of advanced grid management technologies, energy storage solutions, and demand response mechanisms. Moreover, while electricity generation has seen the most significant decarbonization progress, other sectors such as transportation, heating, and industrial processes continue to lag behind.

1.3 Key International Agreements

International cooperation has played a crucial role in shaping the global energy transition, with several landmark agreements and initiatives providing the framework for collective action. Chief among these is the Paris Agreement, adopted in 2015 under the United Nations Framework Convention on Climate Change (UNFCCC). The agreement established a goal of limiting global warming to well below 2°C above pre-industrial levels, with efforts to pursue a more ambitious target of 1.5°C. To achieve this, signatory countries have committed to submitting nationally determined contributions (NDCs) outlining their greenhouse gas reduction targets and climate action plans.

Since the adoption of the Paris Agreement, there have been successive Conferences of the Parties (COP) meetings, where nations review progress and update their commitments [23]. The outcomes of COP28, held in Dubai in 2023, were particularly notable for the first explicit call to "transition away from fossil fuels" in the final text — a milestone in international climate diplomacy. The conference also secured new pledges for climate finance, with developed countries agreeing to increase support for developing nations facing the brunt of climate impacts.

In addition to the UNFCCC process, other international frameworks have emerged to coordinate energy and climate policy. The International Renewable Energy Agency (IRENA), the Clean Energy Ministerial (CEM), and initiatives like Mission Innovation promote technology collaboration, investment mobilization, and best practice sharing. The G20 and G7 summits have also increasingly featured energy transition and climate security as central agenda items, reflecting the growing recognition of energy as a geopolitical issue.

1.4 Technological and Market Drivers in the Energy Transition

Technological innovation and market dynamics are at the heart of the global energy transition [24]. Over the past decade, dramatic cost reductions in renewable energy technologies have fundamentally reshaped the economics of energy production. Solar PV module prices have declined by more than 90% since 2010, while wind turbine costs have halved, enabling rapid deployment in both developed and emerging markets (IRENA, 2023). The advent of utility-scale battery storage and grid management software has further facilitated the integration of variable renewables into electricity systems.

In addition to power generation, new technologies are emerging to decarbonize hard-to-abate sectors. Green hydrogen, produced through electrolysis powered by renewable energy, is gaining traction as a potential solution for industries such as steelmaking, chemicals, and long-haul transport. Pilot projects and early commercial plants are now operational in Europe, the Middle East, and Asia, supported by government subsidies and industrial partnerships.

Carbon capture, utilization, and storage (CCUS) technologies have also seen renewed interest, particularly in North America and the Middle East, as a means of reducing emissions from fossil fuel-based power generation and industrial processes [25]. While commercial deployment remains limited, recent policy incentives such as the U.S. Inflation Reduction Act and the EU's Carbon Border Adjustment Mechanism (CBAM) are expected to accelerate investment in this field.

In summary, the global energy landscape is characterized by a dynamic interplay of demand growth, shifting supply patterns, technological disruption, and geopolitical recalibration. While the long-term trajectory points towards a cleaner, more diversified energy system, the pace and pathway of this transition will remain uneven across regions and sectors, shaped by policy choices, market conditions, and international cooperation.

2. CHINA'S ENERGY STRATEGY

China's rise as a global power over the past few decades has been marked by an insatiable appetite for energy. As the world's most populous country and the second-largest economy, China faces the complex task of securing a reliable and sustainable energy supply while also addressing environmental concerns and fulfilling its ambition to be a global leader in green technology. This section examines China's energy strategy in detail, focusing on its strategic priorities, key policy instruments, renewable energy initiatives, fossil fuel dependency, technological innovation, and energy diplomacy efforts [26]. Through this analysis, it becomes clear how China is attempting to balance rapid economic growth with energy security, environmental sustainability, and geopolitical influence.

2.1 Strategic Priorities: Energy Security, Economic Growth, and Global Leadership

At the core of China's energy strategy lies the challenge of maintaining energy security. Given its immense population and industrial capacity, China is the world's largest energy consumer and, since 2006, the largest emitter of carbon dioxide. A significant proportion of its energy is still derived from coal, a domestic resource that has historically ensured a degree of self-sufficiency. However, reliance on imported oil and gas—particularly from geopolitically volatile regions has heightened concerns over supply disruptions. As a result, securing stable, diversified, and affordable energy supplies remains a top strategic priority for the Chinese government. Alongside energy security, economic growth continues to be a central pillar of China's national strategy. Since the late 1970s, when the country embarked on a path of economic liberalization, rapid industrialization has driven up energy demand at an unprecedented rate. The government views access to abundant energy as essential for sustaining industrial output, urbanization, and improving the standard of living for its citizens. In recent years, China has also sought to assert global leadership in clean energy technologies and climate governance [27]. Recognizing the growing international emphasis on climate change, China has positioned itself as a proactive participant in global climate initiatives, while simultaneously promoting its domestic renewable energy industries as sources of future economic competitiveness and soft power. This ambition is reflected in its stated aim to peak carbon emissions before 2030 and achieve carbon neutrality by 2060, a pledge that marked a significant shift in its strategic orientation (Fig. 2).

Fig 2. China's Energy Strategy: Balancing Priorities

2.2 Policy Instruments: Five-Year Plans and the Carbon Neutrality Target

China's energy policy is primarily guided by its Five-Year Plans (FYPs), which set national development priorities and quantitative targets for a range of sectors, including energy. The 13th FYP (2016–2020) laid considerable emphasis on reducing coal consumption, increasing the share of non-fossil fuels, and improving energy efficiency. This trend has continued under the 14th FYP (2021–2025), which emphasizes the importance of transitioning to a low-carbon economy, accelerating the deployment of renewables, and enhancing domestic energy security [28]. The carbon neutrality target announced in September 2020 by President Xi Jinping represents a landmark policy commitment. Though initially met with skepticism given China's heavy coal dependence, the government has since begun integrating this objective into its policy frameworks. This includes tightening controls on new coal-fired power plants, investing heavily in renewable infrastructure, and fostering research in low-carbon technologies such as hydrogen and energy storage. The target also influences regional and provincial energy policies, with local governments adjusting their development plans to align with national climate goals.

Additionally, China employs a range of market-based mechanisms and administrative controls to manage its energy sector. These include subsidies for renewable energy projects, mandatory renewable energy quotas for utilities, emissions trading schemes (ETS), and administrative caps on energy consumption growth. The national carbon market, launched in 2021 for the power sector, is expected to gradually expand to cover other high-emission industries, thereby creating economic incentives for emissions reductions.

2.3 Renewable Energy Development: Solar, Wind, Hydropower, and Nuclear

China has made remarkable strides in renewable energy development over the past two decades and now leads the world in terms of installed capacity for solar, wind, and hydropower. This rapid expansion is driven by both environmental imperatives and economic considerations, as renewables offer a means of reducing air pollution, lowering greenhouse gas emissions, and decreasing dependence on imported fuels [28, 29].

In the solar energy sector, China is both the largest manufacturer and installer of photovoltaic (PV) panels globally. By the end of 2023, the country had exceeded 500 GW of installed solar capacity, with ambitious plans to reach over 1,200 GW by 2030. Subsidies, favorable financing conditions, and local government support have spurred a solar boom, particularly in western provinces with abundant sunlight and land availability.

Hydropower remains a vital component of China's energy mix, accounting for around 17% of total electricity generation in 2023 [30]. Iconic projects such as the Three Gorges Dam and the Baihetan hydropower station highlight China's capacity for large-scale infrastructure development. However, environmental and social concerns, including the displacement of communities and ecological degradation, have led to greater scrutiny of new hydropower projects.

In the nuclear energy sector, China is accelerating the construction of new reactors as a means of providing stable, low-carbon baseload power. As of 2024, China operates 55 nuclear reactors, with 23 more under construction, and has plans to triple its nuclear capacity by 2035. Technological self-reliance is a key aspect of its nuclear policy, with indigenous reactor designs such as the Hualong One being promoted for both domestic use and export.

2.4 Fossil Fuel Use and Domestic Production

Despite its renewable energy ambitions, China remains heavily reliant on coal, which accounted for approximately 55% of total energy consumption in 2023. While the government has committed to reducing coal's share in the energy mix, it continues to support domestic coal production to safeguard energy security and avoid economic disruptions. Recent energy shortages and geopolitical tensions, notably the fallout from the Russia-Ukraine conflict, have reinforced the importance of maintaining a robust domestic coal supply. China is also the world's largest oil importer, with much of its crude supply coming from the Middle East, Russia, and Africa. In response to concerns over import dependency, China has invested in strategic petroleum reserves and sought to diversify its supplier base. Additionally, the development of domestic unconventional oil and gas resources, including shale gas and coal-bed methane, has become a strategic priority [31].

Natural gas consumption has grown rapidly over the past decade, driven by efforts to reduce air pollution and decarbonize the power and industrial sectors. China is expanding its liquefied natural gas (LNG) import capacity and has signed long-term contracts with key suppliers such as Qatar and the United States. Domestic gas production, though growing, still lags behind demand, making energy diversification an ongoing necessity.

2.5 Technological Innovation: EVs, Hydrogen, and Smart Grids

China has emerged as a global leader in energy-related technological innovation, particularly in the fields of electric vehicles (EVs), hydrogen energy, and smart grid infrastructure. The government views these sectors as essential not only for achieving carbon neutrality but also for securing a competitive advantage in the global green economy [32].

The EV market in China is the largest in the world, accounting for over 60% of global EV sales in 2023. Strong government incentives, a comprehensive charging infrastructure, and local manufacturing capabilities have driven this growth. Leading Chinese companies such as BYD and NIO have become prominent players in both domestic and international markets.

Hydrogen energy is another emerging focus area, with China investing in research, pilot projects, and production facilities [33]. The government's Hydrogen Industry Development Plan (2021–2035) outlines ambitions to develop hydrogen for industrial use, heavy transport, and as a potential storage medium for renewable energy.

The modernization of China's electricity grid is critical for integrating variable renewable energy sources and ensuring grid stability. Significant investments are being made in ultra-high-voltage (UHV) transmission lines, energy storage systems, and smart grid technologies. These innovations are intended to support the long-distance transmission of renewable electricity from remote production areas in western China to demand centers in the east (Fig. 3).

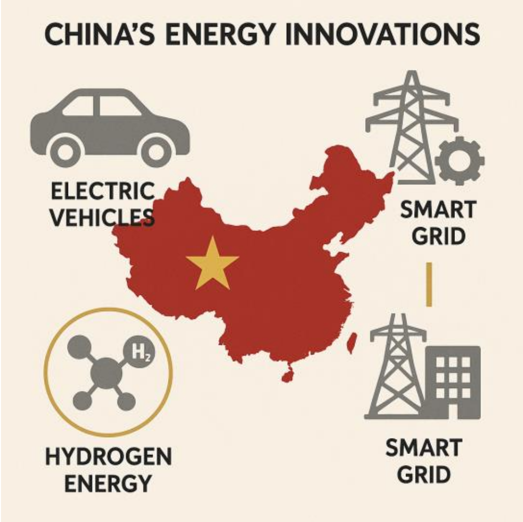

Fig3. China's Energy Innovations: Driving the Green Economy

2.6 Energy Diplomacy: Belt and Road Initiative and International Partnerships

Energy diplomacy has become an increasingly important component of China's broader foreign policy. Through the Belt and Road Initiative (BRI), launched in 2013, China has financed and constructed numerous energy infrastructure projects across Asia, Africa, the Middle East, and Eastern Europe. These projects have included coal, hydropower, solar, and wind power plants, as well as oil and gas pipelines. While initially criticized for supporting coal-fired power abroad, recent policy shifts indicate a move towards promoting clean energy projects under the BRI framework.

China also actively participates in international energy governance institutions such as the International Renewable Energy Agency (IRENA), the International Energy Agency (IEA), and the United Nations Framework Convention on Climate Change (UNFCCC) [34]. Through these platforms, China seeks to shape global energy norms, promote its technological standards, and enhance its geopolitical influence.

Bilateral energy partnerships with key countries—including Russia, Saudi Arabia, Pakistan, and members of the Association of Southeast Asian Nations (ASEAN)—are strategically important for ensuring diversified energy supplies and securing access to critical resources. Joint ventures, technology cooperation agreements, and cross-border energy projects reflect China's pragmatic approach to energy diplomacy.

3. UNITED STATES' ENERGY STRATEGY

The United States, as one of the world's largest economies and historically the largest energy consumer, holds a crucial role in shaping the global energy landscape [34]. Its energy strategy has long been characterized by an interplay of domestic priorities, economic imperatives, environmental considerations, and international geopolitical interests. In recent years, the dynamics of energy policy in the United States have undergone significant transformations, driven by factors such as the shale gas revolution, increasing renewable energy competitiveness, mounting climate change concerns, and shifting global power relations. This section examines the United States' energy strategy in detail, analyzing its strategic priorities, internal policy dynamics, energy production landscape, technological innovations, and international diplomatic engagements in the energy sector.

3.1 Strategic Priorities: Energy Independence, Economic Competitiveness, and Climate Leadership

The core strategic objectives of the United States' energy policy can be broadly categorized into three interconnected goals: achieving energy independence, enhancing economic competitiveness, and asserting climate leadership.

Energy independence has historically been a persistent ambition for successive U.S. administrations, particularly since the 1973 oil crisis, which exposed the vulnerabilities of overreliance on foreign oil imports. The rapid development of domestic shale oil and gas resources over the past two decades enabled the United States to dramatically reduce its dependence on imported energy. By 2019, the U.S. had become a net exporter of energy for the first time in nearly 70 years, marking a symbolic milestone in its quest for energy security.

Climate leadership has increasingly emerged as a priority, especially in the context of mounting evidence of anthropogenic climate change and the growing demands of the international community for decisive action. The

United States' position on climate policy, however, has fluctuated markedly depending on political leadership [35]. While the Obama administration introduced major initiatives such as the Clean Power Plan and committed to the Paris Agreement, the subsequent Trump administration rolled back many of these policies and withdrew from the Paris accord. Under President Biden, the U.S. re-entered the agreement and pledged ambitious climate goals, including achieving net-zero emissions by 2050 and a 50-52% reduction in greenhouse gas emissions by 2030 relative to 2005 levels.

3.2 Federal vs. State-Level Policy Dynamics

One of the distinctive features of the U.S. energy governance system is the division of powers between the federal government and individual states. This division has led to a highly diverse and sometimes fragmented policy landscape, where national strategies coexist with — and occasionally conflict against — state-level initiatives.

At the federal level, energy policy is shaped by legislation passed by Congress, executive orders, regulatory frameworks issued by agencies such as the Department of Energy (DOE) and the Environmental Protection Agency (EPA), and major national initiatives. Key policy instruments include tax incentives for renewable energy, emissions regulations, funding for research and development (R&D), and strategic energy partnerships abroad.

The interplay between federal and state policies has produced both synergies and tensions. On one hand, decentralized governance has fostered policy experimentation and regional leadership. On the other, conflicting priorities between federal and state administrations — particularly during periods of political polarization — have led to regulatory uncertainty and fragmented national strategies.

3.3 Renewable Energy Expansion: Solar, Wind, and Bioenergy

In recent years, the United States has experienced a remarkable surge in renewable energy development, driven by declining technology costs, state mandates, corporate procurement, and public support for clean energy transitions.

Solar power has emerged as one of the fastest-growing sources of electricity generation in the U.S. Utility-scale solar projects have proliferated, particularly in sunny states like California, Texas, Nevada, and Arizona. The distributed solar sector, encompassing residential and commercial rooftop systems, has also expanded rapidly, supported by federal investment tax credits (ITC), net metering policies, and falling installation costs.

Wind energy has become a cornerstone of the U.S. renewable portfolio, especially in the Midwest and Southern Plains states. Texas, in particular, leads the nation in installed wind capacity, followed by Iowa, Oklahoma, and Kansas [36]. Offshore wind, while still in its infancy, has gained momentum with planned projects along the Atlantic coast and substantial leasing auctions by the Bureau of Ocean Energy Management (BOEM).

Bioenergy, including biomass power plants, biofuels, and biogas, continues to play a supplementary role in the U.S. energy mix. Ethanol, primarily derived from corn, remains the dominant biofuel and is blended into gasoline under the Renewable Fuel Standard (RFS) program. Advanced biofuels and waste-to-energy projects are gradually gaining traction, although their scalability remains limited.

3.4 Fossil Fuel Landscape: Shale Gas Boom and Coal Decline

The shale gas revolution stands as one of the most transformative developments in the U.S. energy sector over the past two decades. Enabled by technological advancements in hydraulic fracturing (fracking) and horizontal drilling, shale gas production surged, positioning the U.S. as the world's leading natural gas producer. This abundance of inexpensive natural gas has had far-reaching implications, displacing coal in the power sector, lowering energy prices, and enabling the U.S. to become a major liquefied natural gas (LNG) exporter.

Conversely, coal's decline has been precipitous. Once the dominant source of U.S. electricity generation, coal's share fell from over 50% in 2005 to under 20% by 2023. Factors driving this decline include competition from cheap natural gas, aging coal plants, stricter environmental regulations, and societal opposition to carbon-intensive energy sources [37]. Several major utilities have announced plans to retire coal plants ahead of schedule, and coal mining employment has plummeted [38].

Despite coal's retreat, oil and natural gas production remains robust, particularly in regions like the Permian Basin (Texas and New Mexico), Marcellus Shale (Pennsylvania and West Virginia), and Bakken Formation (North Dakota). The U.S. has capitalized on its hydrocarbon resources to boost domestic energy security and strengthen its geopolitical influence through increased exports.

3.5 Technological Innovation: Carbon Capture, Hydrogen, and Advanced Nuclear

Technological innovation is central to the United States' strategy for balancing energy production, emissions reduction, and economic competitiveness. Several emerging technologies have gained prominence as potential solutions to decarbonize the energy sector while preserving energy security.

Carbon capture, utilization, and storage (CCUS) technologies are receiving growing attention, particularly for mitigating emissions from natural gas plants and industrial facilities. The federal government has introduced tax credits (45Q incentives) and funding initiatives to support CCUS projects, including pioneering efforts in Texas and Louisiana.

Hydrogen energy is increasingly viewed as a versatile clean energy carrier with applications in power generation, transportation, and industrial processes [39]. The Biden administration's Hydrogen Energy Earthshot initiative aims to reduce the cost of clean hydrogen to $1 per kilogram by 2031, positioning the U.S. as a leader in the global hydrogen economy.

Advanced nuclear reactors, including small modular reactors (SMRs) and Generation IV designs, are also part of the national strategy for achieving net-zero emissions. Proponents argue that next-generation nuclear technologies offer enhanced safety, flexibility, and affordability compared to traditional reactors. Several demonstration projects, such as the NuScale SMR initiative, are underway with federal support.

3.6 Energy Diplomacy: Global Alliances, Indo-Pacific Strategy, and Climate Summits

Energy diplomacy forms a critical component of the United States' broader foreign policy, leveraging energy resources, technologies, and alliances to advance strategic interests and promote global stability.

The U.S. has actively engaged in global energy alliances through platforms such as the International Energy Agency (IEA), Clean Energy Ministerial (CEM), and Major Economies Forum on Energy and Climate (MEF). These initiatives aim to facilitate international collaboration on energy security, renewable deployment, and climate action.

The Indo-Pacific strategy reflects a geopolitical pivot toward countering China's influence in the Asia-Pacific region. Energy cooperation with allies such as Japan, South Korea, India, and Australia has included LNG exports, infrastructure investments, and joint renewable energy projects. The U.S. seeks to ensure open and secure maritime trade routes for energy commodities, particularly through the South China Sea and Indian Ocean [40]. Participation in global climate summits has also become a platform for the U.S. to assert climate leadership and negotiate international agreements. Under the Biden administration, the U.S. hosted the Leaders Summit on Climate in 2021 and actively participated in COP26 and COP28, advocating for enhanced climate ambitions, methane reduction commitments, and financial support for developing countries.

4. EUROPEAN UNION'S ENERGY STRATEGY

The European Union (EU) has long positioned itself as a global leader in climate policy and sustainable energy development [41]. Its energy strategy reflects a multifaceted effort to balance environmental responsibility, economic competitiveness, and energy security within a diverse political and economic bloc. With 27 member states, the EU faces unique challenges in coordinating a unified energy policy, given the varying energy mixes, import dependencies, and industrial priorities of its members. Nevertheless, through strategic planning and comprehensive policy frameworks, the EU has established ambitious goals aimed at achieving climate neutrality, diversifying its energy sources, and reinforcing its geopolitical position in the global energy landscape.

4.1 Strategic Priorities

At the core of the EU's energy policy lies the commitment to achieve climate neutrality by 2050. This ambitious objective, formalized through the European Climate Law in 2021, makes the EU the first major global actor to set a legally binding target for net-zero greenhouse gas emissions. The climate neutrality goal underpins nearly every facet of the Union's energy strategy, shaping policy priorities, investment decisions, and regulatory frameworks. Another critical priority is the integration of the European energy market. The EU envisions a fully interconnected, competitive, and consumer-centered energy market that allows for efficient cross-border trade of electricity and gas. Market integration not only improves efficiency and reduces costs for consumers but also enhances energy security by enabling member states to share resources in times of shortage or crisis [42].

Furthermore, reducing dependency on energy imports, particularly from geopolitically sensitive regions, has become an increasingly urgent concern. The EU has historically been highly dependent on imported fossil fuels, especially natural gas from Russia. This vulnerability was starkly exposed during the 2022 Russian invasion of Ukraine, which triggered an unprecedented energy crisis in Europe. In response, the EU has accelerated efforts to diversify its energy sources, improve energy efficiency, and expand domestic renewable energy production.

4.2 Major Policy Frameworks

The EU's strategic priorities are operationalized through several comprehensive policy frameworks, the most significant of which is the European Green Deal. Introduced in December 2019, the Green Deal serves as the Union's overarching roadmap for making its economy sustainable by transforming climate and environmental challenges into opportunities. It sets out a broad range of initiatives aimed at promoting clean energy, enhancing biodiversity, fostering sustainable industry, and supporting a just transition for communities and workers affected by decarbonization. Building on the Green Deal, the Fit for 55 package was unveiled in July 2021. This legislative initiative aims to reduce the EU's greenhouse gas emissions by at least 55% by

2030, compared to 1990 levels, placing the bloc on a credible pathway toward climate neutrality. The package includes a revision of key directives and regulations governing renewable energy, energy efficiency, carbon pricing, and transport emissions. Notably, it proposes the expansion of the EU Emissions Trading System (ETS), the introduction of a carbon border adjustment mechanism (CBAM), and stricter emissions performance standards for vehicles [43].

In response to the energy security challenges stemming from the geopolitical fallout of the Ukraine crisis, the EU introduced REPowerEU in May 2022. This plan outlines a strategy to rapidly reduce dependency on Russian fossil fuels, aiming for complete independence "well before 2030." REPowerEU focuses on three main pillars: energy savings, diversification of energy imports, and an accelerated roll-out of renewables. It also promotes joint gas purchasing among EU countries, the development of hydrogen corridors, and increased investment in energy infrastructure.

4.3 Renewable Energy and Emissions Reduction Targets

The EU has consistently set some of the world's most ambitious targets for renewable energy deployment and emissions reduction. Under the Revised Renewable Energy Directive (RED III), adopted as part of the Fit for 55 package, the bloc increased its renewable energy target to 42.5% of final energy consumption by 2030, with an aspiration to reach 45%. This represents a substantial increase from the previous 32% target and necessitates a rapid scaling-up of renewable capacity across sectors such as electricity, heating, cooling, and transport. To support this target, member states are required to revise their National Energy and Climate Plans (NECPs) and submit updated strategies detailing how they will contribute to the collective goal. The EU is particularly focusing on offshore wind, solar photovoltaic (PV), and green hydrogen as priority technologies for decarbonizing its energy system. In terms of emissions reduction, the EU Emissions Trading System (ETS) remains the cornerstone of the bloc's climate policy. Covering around 40% of total EU emissions, the ETS operates on a cap-and-trade principle, setting a declining limit on emissions from power plants, industrial facilities, and airlines. The cap is reduced annually in line with the EU's climate targets, and allowances can be traded to ensure cost-effective emissions reductions. The recent reforms to the ETS under the Fit for 55 package introduce a separate emissions trading system for buildings and road transport, sectors previously excluded from the scheme. This expansion broadens the scope of carbon pricing within the EU, sending a strong market signal for emissions reduction and clean technology adoption across the economy.

4.4 Diversification Away from Russian Gas

One of the most pressing challenges for the EU in recent years has been its reliance on natural gas imports from Russia, which historically accounted for around 40% of the bloc's gas supply. The outbreak of war in Ukraine in 2022 fundamentally altered the EU's energy security calculus, prompting a determined shift to diversify supply sources and reduce dependence on Russian energy.

The REPowerEU plan set the ambitious objective of reducing Russian gas imports by two-thirds within a year and achieving full independence "well before 2030." To achieve this, the EU has intensified efforts to secure alternative gas supplies from countries such as Norway, Algeria, the United States (via LNG exports), and Qatar. LNG infrastructure has been rapidly expanded, with new terminals being developed in Germany, the Netherlands, and the Baltic states [44]. Additionally, the EU has prioritized the completion of key energy infrastructure projects, including interconnectors, reverse flow pipelines, and storage facilities. Energy efficiency measures and demand reduction initiatives have also played a crucial role in easing the supply-demand balance during periods of market tightness.

In parallel, the EU is accelerating the deployment of renewables to permanently reduce its reliance on imported fossil fuels. Solar PV capacity, in particular, is being rapidly expanded, with initiatives like the EU Solar Strategy aiming to double installed capacity by 2025 and reach over 600 GW by 2030 (Fig. 4).

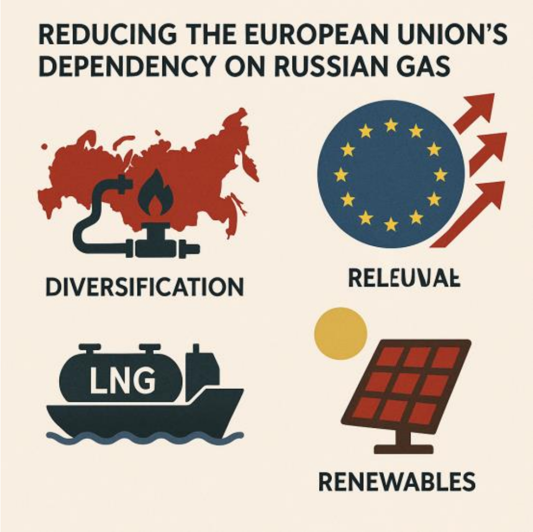

Fig 4. Reducing the European Union's Dependency on Russian Gas

4.5 Technological Innovation

Technological innovation occupies a central place in the EU's energy transition strategy. The bloc recognizes that achieving climate neutrality and energy security requires not only scaling up existing renewable technologies but also investing in next-generation solutions. To this end, the EU has identified several priority areas, including green hydrogen, offshore wind, energy storage, and smart grids.

Green hydrogen is especially important for decarbonizing hard-to-electrify sectors such as heavy industry, aviation, and long-haul transport. The EU Hydrogen Strategy, published in 2020, sets out a roadmap for scaling up renewable hydrogen production, aiming for 10 million tonnes of domestic production and 10 million tonnes of imports by 2030. Projects such as Hydrogen Valleys, cross-border hydrogen corridors, and partnerships with third countries are being promoted to develop a competitive European hydrogen market [45]. Offshore wind energy is another critical pillar, with the EU aiming to increase offshore wind capacity from around 16 GW in 2022 to at least 60 GW by 2030 and 300 GW by 2050. The Offshore Renewable Energy Strategy, released in 2020, outlines measures to facilitate investment, streamline permitting processes, and enhance cross-border cooperation. To address the intermittency of renewables, the EU is heavily investing in energy storage technologies, including batteries, pumped hydro storage, and innovative solutions such as vehicle-to-grid systems. The European Battery Alliance and various Horizon Europe research projects are fostering innovation and supply chain resilience in this sector. Smart grids and digitalization are also priorities, enabling more flexible and efficient management of decentralized renewable energy systems. Investments in grid infrastructure, demand response technologies, and data platforms are crucial for integrating high shares of variable renewables and ensuring system stability.

4.6 Energy Diplomacy

As the EU pursues its internal energy transition goals, it is also reshaping its external energy diplomacy to align with climate objectives and geopolitical realities. The bloc recognizes that its energy security and climate ambitions are deeply interconnected with global developments, particularly in neighboring regions and key supplier countries. One significant area of focus is the EU-Africa energy partnership. The EU seeks to support renewable energy development, grid expansion, and sustainable energy access in African countries while also positioning Africa as a key partner in the global energy transition. Joint initiatives, investment frameworks, and technology transfer agreements are being promoted to foster mutual benefits. In addition, the EU has taken a leading role in advocating for reforms to the Energy Charter Treaty (ECT), an international agreement originally designed to protect cross-border energy investments. The treaty has faced criticism for enabling fossil fuel companies to challenge climate policies through investor-state dispute settlements. The EU has called for modernization of the ECT to ensure alignment with the Paris Agreement and safeguard the right of states to regulate in the public interest. The bloc is also actively engaging in global climate diplomacy through platforms such as the United Nations Framework Convention on Climate Change (UNFCCC), G7, and G20, advocating for stronger climate action, climate finance commitments, and cooperative frameworks for clean technology deployment [46].

5. EUROPEAN UNION'S ENERGY STRATEGY

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Another critical priority is the integration of the European energy market. The EU envisions a fully interconnected, competitive, and consumer-centered energy market that allows for efficient cross-border trade of electricity and gas. Market integration not only improves efficiency and reduces costs for consumers but also enhances energy security by enabling member states to share resources in times of shortage or crisis. Furthermore, reducing dependency on energy imports, particularly from geopolitically sensitive regions, has become an increasingly urgent concern. The EU has historically been highly dependent on imported fossil fuels, especially natural gas from Russia. This vulnerability was starkly exposed during the 2022 Russian invasion of Ukraine, which triggered an unprecedented energy crisis in Europe. In response, the EU has accelerated efforts to diversify its energy sources, improve energy efficiency, and expand domestic renewable energy production.

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Building on the Green Deal, the Fit for 55 package was unveiled in July 2021. This legislative initiative aims to reduce the EU’s greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels, placing the bloc on a credible pathway toward climate neutrality. The package includes a revision of key directives and regulations governing renewable energy, energy efficiency, carbon pricing, and transport emissions. Notably, it proposes the expansion of the EU Emissions Trading System (ETS), the introduction of a carbon border adjustment mechanism (CBAM), and stricter emissions performance standards for vehicles [47].

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To support this target, member states are required to revise their National Energy and Climate Plans (NECPs) and submit updated strategies detailing how they will contribute to the collective goal. The EU is particularly focusing on offshore wind, solar photovoltaic (PV), and green hydrogen as priority technologies for decarbonizing its energy system.

In terms of emissions reduction, the EU Emissions Trading System (ETS) remains the cornerstone of the bloc's climate policy. Covering around 40% of total EU emissions, the ETS operates on a cap-and-trade principle, setting a declining limit on emissions from power plants, industrial facilities, and airlines. The cap is reduced annually in line with the EU's climate targets, and allowances can be traded to ensure cost-effective emissions reductions.

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In parallel, the EU is accelerating the deployment of renewables to permanently reduce its reliance on imported fossil fuels. Solar PV capacity, in particular, is being rapidly expanded, with initiatives like the EU Solar Strategy aiming to double installed capacity by 2025 and reach over 600 GW by 2030.

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One significant area of focus is the EU-Africa energy partnership. The EU seeks to support renewable energy development, grid expansion, and sustainable energy access in African countries while also positioning Africa as a key partner in the global energy transition. Joint initiatives, investment frameworks, and technology transfer agreements are being promoted to foster mutual benefits.

In addition, the EU has taken a leading role in advocating for reforms to the Energy Charter Treaty (ECT), an international agreement originally designed to protect cross-border energy investments [48]. The treaty has faced criticism for enabling fossil fuel companies to challenge climate policies through investor-state dispute settlements. The EU has called for modernization of the ECT to ensure alignment with the Paris Agreement and safeguard the right of states to regulate in the public interest.

The bloc is also actively engaging in global climate diplomacy through platforms such as the United Nations Framework Convention on Climate Change (UNFCCC), G7, and G20, advocating for stronger climate action, climate finance commitments, and cooperative frameworks for clean technology deployment [49].

6. COMPARATIVE ANALYSIS

The global energy transition is one of the defining challenges of the 21st century, with major economies such as China, the United States, and the European Union playing leading roles in shaping the direction, speed, and scope of this transformation. While these actors share certain overarching priorities — notably climate mitigation, energy security, and the promotion of technological innovation — their specific approaches often diverge due to differences in political systems, economic structures, resource endowments, and geopolitical ambitions. This section offers a comparative analysis of the energy strategies pursued by these key global actors, focusing on their common trends and divergences, the geopolitical and security implications of their energy policies, and their respective influences on global energy governance frameworks.

6.1 Common Trends and Shared Priorities

Despite their varying domestic contexts and strategic interests, China, the United States, and the European Union have converged on several core energy policy priorities in recent years [50]. Chief among these is the urgent need to address climate change through ambitious decarbonisation policies. All three actors have formally committed to long-term climate goals, aligning themselves — at least rhetorically — with the objectives of the Paris Agreement.

6.2 Divergences in Energy Strategies

While common priorities are evident, significant divergences remain in the specific approaches adopted by China, the United States, and the European Union, particularly regarding their treatment of fossil fuels, styles of energy diplomacy, and regulatory frameworks.

6.3 Geopolitical Implications and Energy Security Concerns

The energy strategies pursued by China, the United States, and the European Union have far-reaching geopolitical implications, particularly regarding energy security and the shifting balance of power in global energy markets.For the European Union, the war in Ukraine has underscored the vulnerabilities associated with energy import dependency, prompting an accelerated shift toward renewables and alternative suppliers. Energy security concerns now align more closely with climate goals, as both objectives necessitate reducing fossil fuel reliance.The United States’ position as a major oil and gas producer affords it greater flexibility, though its allies' energy security concerns — particularly in Europe and Asia — influence its energy diplomacy. U.S. LNG exports have gained strategic importance, while domestic debates over the environmental impacts of fossil fuel exports continue.China faces a dual challenge of sustaining economic growth while reducing reliance on imported fossil fuels. Energy security considerations drive investments in both renewables and domestic coal capacity, as well as strategic partnerships with resource-rich countries. Beijing's efforts to secure critical minerals for battery and renewable technology production also carry geopolitical ramifications, contributing to tensions with the United States and the EU.

6.4 Influence on Global Energy Governance Structures

Finally, the differing energy strategies of these actors shape their roles within global energy governance frameworks. The European Union has sought to modernise international energy institutions to reflect climate imperatives, advocating for reforms in the Energy Charter Treaty and promoting multilateral cooperation through the Clean Energy Ministerial and the International Renewable Energy Agency (IRENA).

The United States, while historically influential in institutions like the International Energy Agency (IEA), has oscillated in its commitment to multilateral energy cooperation. Under the Biden administration, the U.S. has re-engaged with climate-focused initiatives and resumed leadership in forums such as the Major Economies Forum.

China, increasingly active in global energy governance, has sought to shape norms through the Asian Infrastructure Investment Bank and partnerships within the Belt and Road framework. Its growing influence in renewable energy markets allows it to play a decisive role in setting industry standards and supply chain dynamics.

7. FUTURE OUTLOOK

The future of global energy governance is entering a decisive phase, where the competing priorities of climate mitigation, economic competitiveness, and geopolitical influence are reshaping both national strategies and international frameworks. As major actors like China, the United States, and the European Union pursue their respective energy transitions, the opportunities for cooperation, as well as the risks of fragmentation, are growing. In this section, the potential for collaborative mechanisms, the structural challenges ahead, and the feasibility of establishing a multilateral governance framework for energy are explored.

7.1 Potential Cooperative Frameworks

One of the most encouraging aspects of the evolving global energy landscape is the increasing recognition among states of the shared nature of climate and energy challenges [11, 51]. Despite existing geopolitical rivalries, there are clear incentives for major economies to collaborate in key areas, particularly where mutual benefits can be realized without compromising strategic interests.

Climate Finance

Perhaps the most immediately actionable domain is climate finance. The commitments made under the Paris Agreement, including the pledge by developed nations to mobilize $100 billion annually in climate finance for developing countries, remain critical. Beyond the moral imperative, the strategic rationale is clear: stabilizing energy systems in the Global South is essential for preventing climate-induced migration, economic instability, and geopolitical unrest, all of which have global repercussions [52].

China, the EU, and the US, though with different approaches, have vested interests in this field. The European Union, through its Green Deal and Global Gateway initiative, has signaled its willingness to direct significant funding towards renewable energy projects, grid development, and energy efficiency programs in Africa and Southeast Asia. Similarly, the United States has, under recent administrations, increased its engagement in international climate finance, although domestic political dynamics occasionally complicate the scale and consistency of its commitments. China’s role is somewhat paradoxical. While it continues to invest in overseas fossil fuel infrastructure through the Belt and Road Initiative (BRI), it has also emerged as the world’s largest financier of renewable energy projects abroad. The future will likely see a recalibration of these investments as international pressure mounts and recipient countries increasingly prioritize sustainable energy solutions.

An expanded, jointly administered climate finance platform involving these major powers could serve as a stabilizing mechanism in global energy governance [53]. Such a framework could standardize financing terms, promote transparency, and pool resources for large-scale renewable energy projects, particularly in regions with weak infrastructure and high renewable potential.

Technology Sharing

Technological innovation is the engine of the global energy transition, and while it often serves as a competitive advantage for states, history has shown that cooperative technology development can accelerate collective progress [54]. Joint ventures in nuclear safety, offshore wind development, and electric vehicle (EV) standardization are already underway in some multilateral contexts, but there remains considerable untapped potential. A particularly promising area for cooperation lies in the development of green hydrogen. As an emerging vector for decarbonizing hard-to-abate sectors like steel, cement, and heavy transport, hydrogen technology is still at a nascent stage, with costs and infrastructure presenting significant barriers. A coordinated international effort to establish shared standards, invest in cross-border infrastructure, and de-risk private investments could dramatically accelerate the commercialization of hydrogen technologies. Similarly, smart grid and energy storage technologies, essential for managing the intermittency of renewable energy, present opportunities for knowledge exchange and joint pilot projects [55]. The EU's experience with integrated electricity markets and cross-border grid interconnectivity could be particularly valuable for China and the US as they navigate the complexities of integrating decentralized renewable generation at scale.

Grid Interconnectivity

Interconnected energy grids have long been proposed as a means of enhancing energy security, market efficiency, and renewable energy uptake. In practice, however, geopolitical concerns and technical challenges have often stymied progress. Nonetheless, regional grid initiatives have gained momentum in recent years, and there is potential for these to serve as building blocks for broader cooperative frameworks. Europe has led in this area, with its highly integrated electricity market allowing for cross-border trading and balancing of variable renewable generation. China has pursued its own regional initiatives, particularly with neighboring Southeast Asian countries, while the US has engaged in discussions around expanded interconnections with Canada and Mexico.

A future scenario might involve linking regional grids through high-voltage direct current (HVDC) transmission lines, facilitating the transfer of renewable energy across time zones and demand centers. Such interconnectivity could reduce the need for costly storage solutions and lower system-wide emissions. Realizing this vision, however, would require unprecedented levels of regulatory alignment, political trust, and infrastructure investment — conditions that remain elusive in the current international climate but are not beyond reach.

7.2 Challenges and Risks

While the opportunities for cooperative frameworks are evident, they are accompanied by substantial challenges and risks. These range from geopolitical rivalries and protectionist tendencies to structural barriers within domestic energy markets [16].

Geopolitical Tensions

The relationship between energy strategy and geopolitics is historically entrenched, and the current global landscape is no exception. US-China tensions, in particular, have significant implications for global energy governance. Disputes over trade, intellectual property, and security concerns around critical infrastructure — including grid equipment and energy storage systems — complicate efforts at technological cooperation. Similarly, the European Union's efforts to assert strategic autonomy in energy policy, particularly in the wake of the Russian invasion of Ukraine, have led to a recalibration of its external partnerships. While the EU remains committed to multilateralism, its prioritization of energy security has occasionally conflicted with broader climate diplomacy objectives.

These geopolitical tensions risk creating a fragmented global energy landscape, with parallel systems and standards emerging in competing blocs.

This would not only slow the pace of the global energy transition but also increase costs and create inefficiencies in international energy markets.

7.3 Prospects for a Multilateral Energy Governance Model

Given the scale of the challenges and the growing interdependence of global energy systems, the question arises whether a coherent multilateral energy governance model is feasible. Existing institutions, such as the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA), play important roles, but their mandates and memberships reflect past energy realities and are sometimes ill-suited to contemporary needs.

A future multilateral framework would need to be inclusive, adaptable, and capable of addressing the full spectrum of energy issues — from fossil fuel phase-out to renewable deployment, grid interconnectivity, technology standardization, and climate finance. It would also need to reconcile the competing interests of established powers, emerging economies, and developing states.

One potential pathway could involve the strengthening of existing institutions through expanded mandates and membership. For instance, the IEA has recently opened its doors to major emerging economies, including China and India, while IRENA's focus on renewables positions it well for an expanded role in the coming decades.

Alternatively, a new multilateral energy forum could be established, modeled on the G20's informal, flexible structure. Such a body could facilitate regular dialogue among major emitters and energy producers, coordinate policy responses to crises, and serve as a platform for negotiating cooperative initiatives in climate finance and technology development [56].

Ultimately, the prospects for such a model will depend on the political will of major powers to prioritize collective long-term interests over short-term strategic gains. The coming decade will likely determine whether the global energy transition proceeds in a fragmented, competitive manner or through coordinated, multilateral action.

CONCLUSION

As this chapter has explored, the energy strategies of the world's major actors—China, the United States, and the European Union—are evolving rapidly in response to mounting pressures from climate change, energy security concerns, and shifting geopolitical landscapes. Each actor approaches the energy transition with distinct priorities and policy tools, shaped by their unique economic conditions, political structures, and strategic goals. Yet, despite these differences, common threads emerge that illustrate the complex and interconnected nature of global energy governance.

A central takeaway from this analysis is that while China, the US, and the EU all acknowledge the urgent need to transition toward low-carbon energy systems, their paths diverge considerably in how they balance economic growth, environmental objectives, and geopolitical considerations.

China's energy strategy is characterized by an aggressive push toward renewable energy deployment alongside continued reliance on fossil fuels, particularly coal, to maintain energy security and support rapid industrial growth. The country's commitment to achieving carbon neutrality by 2060 reflects a long-term vision, but in the near term, China continues to navigate the trade-offs between development and decarbonization. Its use of state-driven Five-Year Plans enables coordinated investments in clean technology, while international initiatives like the Belt and Road expand its energy influence across developing regions.

The United States exhibits a more fragmented but no less ambitious approach, with federal policies encouraging renewables and emissions reductions while some states maintain divergent agendas. The shale gas revolution has dramatically reshaped the US energy landscape, offering a transitional fuel that has helped reduce coal's share but also raised questions about methane emissions. Technological innovation remains a cornerstone of the US strategy, with significant investment in advanced nuclear, carbon capture, and hydrogen technologies. On the international stage, the US leverages energy diplomacy to reinforce alliances and promote market-driven solutions.

The European Union stands out for its strong regulatory frameworks and binding climate targets, aiming for climate neutrality by 2050 through ambitious programs like the European Green Deal. The EU's energy strategy stresses energy efficiency, renewable expansion, and a strategic shift away from Russian fossil fuel dependence, especially in light of recent geopolitical tensions. Integration of energy markets, coupled with a focus on innovation in green hydrogen and offshore wind, marks the EU's path toward a sustainable and secure energy future. Additionally, its energy diplomacy emphasizes multilateral cooperation and support for global climate goals.

When viewed comparatively, these strategies reveal both convergences and tensions. All three actors invest heavily in renewables and innovation, underscoring a global consensus on the importance of clean energy. Yet divergences in fossil fuel use, market structures, and diplomatic approaches highlight the challenges of aligning national interests with global climate imperatives. This fragmented landscape complicates efforts to forge unified global energy governance but also reflects the need for flexible, context-sensitive frameworks that accommodate diverse realities.

Implications for Policymakers, Industry, and Academia

The findings of this chapter carry important implications across multiple spheres. For policymakers, the key lesson is that crafting effective energy strategies requires not only setting ambitious climate targets but also designing integrated policies that address economic competitiveness, social equity, and geopolitical stability simultaneously. The varied approaches of China, the US, and the EU demonstrate that there is no one-size-fits-all solution; instead, policy must be tailored to local circumstances while fostering international cooperation. Policymakers should prioritize transparency, data sharing, and regulatory harmonization to build trust and reduce barriers to cross-border clean energy trade and investment.

For industry leaders, the chapter underscores the need to remain agile and forward-looking amid shifting policy landscapes and technological breakthroughs. Firms involved in renewable energy, energy storage, grid management, and emerging technologies such as hydrogen will find expanding opportunities, but also heightened competition. Understanding the strategic priorities and regulatory environments of different regions can inform better investment decisions and partnership strategies. Moreover, industry has a critical role in supporting workforce transitions and ensuring that energy innovation translates into affordable, reliable services for consumers.

Academic research stands to benefit from these insights by deepening the study of energy policy integration and multilateral governance. Future work could explore how emerging technologies interact with market reforms and geopolitical dynamics to shape the pace and fairness of the energy transition. There is also a pressing need for interdisciplinary research that bridges engineering, economics, political science, and environmental studies to provide holistic policy recommendations. Comparative case studies, scenario modeling, and stakeholder analyses can offer valuable perspectives to both scholars and practitioners.

Suggestions for Further Research

Building on the foundations laid in this chapter, several avenues for future research emerge as particularly promising. First, more granular investigations into the subnational and regional variations within these major actors could shed light on the internal dynamics influencing national energy strategies. For instance, exploring the role of US states or Chinese provinces in driving innovation and policy experimentation would enrich understanding of decentralized energy governance.

Second, the interplay between energy security and climate goals warrants deeper exploration, especially in light of recent geopolitical shocks and supply chain disruptions. Future research could examine how energy import dependencies affect strategic decision-making and the resilience of clean energy systems.

Third, the role of emerging technologies such as green hydrogen, advanced nuclear, and digital energy management deserves expanded attention. While this chapter has highlighted their strategic importance, detailed techno-economic assessments and pilot project evaluations could help clarify their scalability and policy needs.

Fourth, international cooperation mechanisms and conflict resolution frameworks in energy governance remain underexplored. Scholars could investigate how diplomatic efforts, trade agreements, and global institutions can evolve to better manage competing interests and accelerate the global energy transition.

Finally, social dimensions of the energy transition—including equity, just transition policies, and public acceptance—merit comprehensive study. Understanding how communities experience and influence energy transformations is critical for designing inclusive policies that garner broad support.

In conclusion, the energy strategies of China, the United States, and the European Union reflect the complexity of navigating climate ambition, economic growth, and geopolitical realities in an interconnected world. While their paths vary, all three contribute indispensable pieces to the global puzzle of sustainable energy governance. By learning from their experiences and fostering dialogue across borders, there is hope for a more coordinated and effective approach to meeting the pressing energy and climate challenges ahead.

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