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Evaluating Regulatory Frameworks for Decarbonization: Lessons from the United States and Nigeria

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Abstract

Decarbonization stands as a critical imperative in the global pursuit of sustainable development and climate mitigation. This paper presents a comprehensive evaluation of regulatory frameworks for decarbonization, drawing lessons from both the United States (US) and Nigeria. The analysis encompasses a multifaceted exploration of regulatory approaches, stakeholder engagement, adaptive governance, and policy innovation within the context of two distinct yet interconnected socio-economic landscapes. Through a comparative lens, the study illuminates contrasting regulatory strategies employed by these nations, highlighting key similarities, differences, successes, and challenges. In the US, a historical overview reveals the interplay between federal and state-level regulations, showcasing the impact of policies, laws, and incentives on decarbonization efforts. Meanwhile, in Nigeria, an examination of the energy landscape uncovers the complexities of regulatory frameworks amidst unique socio-economic challenges. Despite disparities, shared experiences offer valuable insights for mutual learning and collaboration. The evaluation identifies effective metrics for assessing regulatory success, emphasizing the importance of stakeholder engagement and policy flexibility in navigating evolving decarbonization challenges. Furthermore, the study explores the role of emerging technologies in driving regulatory innovation, presenting opportunities and challenges for both nations. Ultimately, the paper offers recommendations tailored to enhance regulatory frameworks in the US and Nigeria, urging policymakers, stakeholders, and researchers to leverage international cooperation and knowledge exchange in the pursuit of ambitious decarbonization goals.

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1. Introduction

Decarbonization, the systematic reduction of carbon emissions, has increasingly become a critical imperative in the global effort to mitigate climate change and ensure a sustainable future (Wimbadi, and Djalante, 2020; Vatalis, *et al.*, 2022). Central to the success of decarbonization efforts are robust regulatory frameworks that provide the necessary incentives, guidelines, and mechanisms to facilitate the transition towards low-carbon economies. These frameworks play a pivotal role in shaping the behavior of industries, businesses, and individuals, influencing investment decisions, technological innovation, and societal norms.

Moreover, they serve as essential tools for governments to fulfill their commitments under international agreements such as the Paris Agreement, which aims to limit global warming to well below 2 degrees Celsius.

In examining the regulatory frameworks for decarbonization, this paper directs its focus on two nations with distinct socio-economic contexts and energy landscapes: the United States (US) and Nigeria. The United States stands as one of the world's largest economies and energy consumers, with a complex regulatory framework characterized by a mix of federal, state, and local regulations. It has a long history of environmental policies, including landmark legislation such as the Clean Air Act and the Clean Power Plan. Conversely, Nigeria, as Africa's most populous country and a major oil producer, faces unique challenges in balancing economic development with environmental sustainability. Its regulatory framework reflects a blend of national policies, international commitments, and local dynamics, shaped by factors such as resource dependence, infrastructure limitations, and socio-political complexities (Penttinen, 2022; Rhodes, *et al.*, 2021; Eisinger, 1988).

Through a comparative analysis of these contrasting contexts, this study aims to elucidate the strengths, weaknesses, opportunities, and threats inherent in regulatory approaches to decarbonization. By delving into the intricacies of regulatory governance, the paper seeks to extract valuable lessons learned and identify best practices that can inform policy formulation and implementation in both nations. Furthermore, it endeavors to foster dialogue and collaboration between stakeholders, policymakers, and researchers across borders, recognizing the interconnected nature of the global energy transition. In essence, this evaluation contributes to the broader discourse on decarbonization by providing insights into the role of regulatory frameworks as catalysts for sustainable development and climate action.

1.1 Research Gap

Research Gap Analysis for Evaluating Regulatory Frameworks for Decarbonization: Lessons from the United States and Nigeria

Decarbonization initiatives have gained considerable attention globally, with various countries implementing regulatory frameworks to drive the transition towards low-carbon economies. However, despite the increasing focus on decarbonization, there exists a notable gap in the literature regarding the comparative analysis of regulatory frameworks between developed and developing countries, specifically between nations such as the United States (US) and Nigeria. This research aims to address this gap by conducting a comprehensive evaluation of regulatory approaches to decarbonization in these two distinct contexts (Idoko, *et al.*, 2024; Apulu, 2012; Wang, 2019).

One of the primary research gaps pertains to the limited comparative analysis of regulatory frameworks for decarbonization across diverse socio-economic landscapes. Existing studies often focus on case studies within either developed or developing countries, thereby overlooking the contrasts and commonalities between nations at different stages of economic development. By conducting a comparative analysis between the US and Nigeria, this research seeks to fill this gap by providing insights into the unique challenges and opportunities faced by countries with varying levels of economic development and energy

infrastructure (Juszczak, 2023; Upham, *et al.*, 2022).

Furthermore, there is a dearth of research specifically examining the effectiveness of regulatory frameworks for decarbonization in the context of resource-rich developing countries such as Nigeria. While studies on decarbonization often highlight the experiences of developed countries with established regulatory regimes, there is a lack of in-depth analysis of the regulatory challenges and policy responses in resource-dependent economies like Nigeria (John, 2012; Asche, and Mainz, 2018; Atadoga, 2024). This research aims to bridge this gap by exploring the complexities of decarbonization regulation in Nigeria, considering factors such as the dominance of fossil fuels, infrastructure limitations, and socio-political dynamics. Moreover, existing literature on decarbonization often overlooks the role of stakeholder engagement and adaptive governance in shaping regulatory frameworks. While regulatory policies are crucial for driving decarbonization, their effectiveness is contingent upon meaningful engagement with stakeholders and the ability to adapt to evolving socio-economic and environmental circumstances. This research seeks to address this gap by examining the role of stakeholder participation, policy flexibility, and adaptive governance in the design and implementation of regulatory frameworks for decarbonization in both the US and Nigeria.

In summary, the research gap analysis highlights the need for a comparative examination of regulatory frameworks for decarbonization between developed and developing countries, with a specific focus on resource-rich economies such as Nigeria. By addressing these gaps, this research aims to contribute to a more nuanced understanding of the challenges and opportunities associated with regulatory approaches to decarbonization in diverse global contexts.

2. Understanding Decarbonization

Decarbonization, the process of reducing carbon dioxide (CO₂) emissions and minimizing carbon footprints, has emerged as a crucial strategy in mitigating climate change and transitioning towards sustainable energy systems. It encompasses a wide range of measures aimed at reducing reliance on fossil fuels, increasing energy efficiency, and promoting the use of renewable energy sources (Nakićenović, 1996; Jackson, *et al.*, 2018). The significance of decarbonization lies in its potential to curb greenhouse gas emissions, limit global warming, and mitigate the adverse impacts of climate change on ecosystems, economies, and human well-being.

At its core, decarbonization involves shifting away from carbon-intensive energy sources such as coal, oil, and natural gas towards cleaner alternatives such as wind, solar, hydroelectric, and nuclear power. By reducing the carbon intensity of energy production and consumption, decarbonization can significantly decrease the emissions of greenhouse gases responsible for global warming. This transition is essential to achieve the targets set forth in international agreements such as the Paris Agreement, which aims to limit global warming to well below 2 degrees Celsius above pre-industrial levels. Decarbonization efforts involve multiple sectors and industries that contribute to carbon emissions, including energy, transportation, industry, agriculture, and buildings. In the energy sector, decarbonization entails phasing out coal-fired power plants, increasing the share of renewable energy sources in electricity generation, and enhancing energy efficiency in

both production and consumption. The transportation sector plays a crucial role in decarbonization through the electrification of vehicles, the expansion of public transportation systems, and the promotion of alternative fuels such as biofuels and hydrogen. In the industrial sector, decarbonization involves implementing energy-efficient technologies, optimizing manufacturing processes, and adopting low-carbon fuels and feedstocks. Agriculture and land use also play a vital role in decarbonization, with practices such as sustainable land management, reforestation, and soil carbon sequestration helping to reduce emissions from deforestation, agriculture, and land degradation. Finally, decarbonizing buildings involves improving energy efficiency in construction, heating, and cooling systems, as well as integrating renewable energy technologies such as solar panels and geothermal heat pumps (Ramirez-Corredores, *et al.*, 2023; Serrano, 2022; Ibeh, *et al.*, 2024).

To accelerate decarbonization efforts and achieve meaningful emissions reductions, governments, businesses, and civil society organizations have launched various global initiatives and set ambitious targets. One such initiative is the Sustainable Development Goals (SDGs) adopted by the United Nations, which include specific targets related to climate action, clean energy, and sustainable cities. Additionally, the Paris Agreement, signed by nearly 200 countries, sets a collective goal of limiting global warming to well below 2 degrees Celsius and pursuing efforts to limit it to 1.5 degrees Celsius. To achieve this goal, countries have committed to nationally determined contributions (NDCs) outlining their plans to reduce emissions and enhance resilience to climate change. In addition to international agreements, many countries and regions have established their own decarbonization targets and initiatives. For example, the European Union has set a target of achieving net-zero greenhouse gas emissions by 2050, with interim targets for reducing emissions by 2030. Similarly, individual countries such as the United Kingdom, Japan, and South Korea have announced ambitious plans to achieve net-zero emissions within the coming decades. In the United States, the Biden administration has pledged to rejoin the Paris Agreement and pursue aggressive climate action, including decarbonizing the electricity sector by 2035 and achieving net-zero emissions economy-wide by 2050 (Nieto, 2022; Plötz, *et al.*, 2021; Adefemi, *et al.*, 2021).

Overall, decarbonization represents a critical pathway towards a more sustainable and resilient future, offering solutions to address the urgent challenges of climate change while also unlocking opportunities for economic growth, innovation, and social equity. By understanding the definition, significance, key sectors, industries, and global initiatives of decarbonization, stakeholders can better navigate the transition towards a low-carbon economy and contribute to the collective effort to safeguard the planet for future generations.

2.1 Regulatory frameworks in the United States

The United States has a rich history of regulatory approaches to decarbonization, shaped by a combination of federal, state, and local initiatives aimed at addressing environmental challenges and promoting sustainable development. Historically, the US has taken significant steps to regulate emissions of pollutants, including carbon dioxide (CO₂), from various sectors such as energy, transportation, industry, and buildings. The evolution of US regulatory frameworks

reflects changing societal attitudes towards environmental protection, advances in scientific understanding of climate change, and shifts in political priorities (Labonte, 2017; Oberweis, *et al.*, 2020).

At the federal level, landmark legislation such as the Clean Air Act (CAA) has served as the cornerstone of US environmental policy since its enactment in 1970. The CAA, amended several times over the years, provides the Environmental Protection Agency (EPA) with the authority to regulate air pollutants, including criteria pollutants such as particulate matter, nitrogen oxides, sulfur dioxide, and carbon monoxide. While the CAA primarily focuses on traditional pollutants, amendments in the 1990s expanded its scope to include greenhouse gases, enabling the EPA to regulate CO₂ emissions from stationary sources such as power plants and industrial facilities. In addition to federal regulations, many states have implemented their own decarbonization policies and initiatives, often surpassing federal requirements and setting more ambitious targets for emissions reductions. States such as California, New York, and Massachusetts have adopted comprehensive climate action plans, renewable energy standards, and cap-and-trade programs to reduce emissions and promote clean energy investments. These state-level regulations complement federal efforts and allow for tailored approaches to address regional challenges and priorities (Ahlers, 2015; Dernbach, and Altenburg, 2014).

Key policies, laws, and incentives promoting decarbonization in the US include a mix of regulatory measures, financial incentives, and market-based mechanisms. For example, the production tax credit (PTC) and investment tax credit (ITC) provide tax incentives for renewable energy projects, encouraging investment in solar, wind, and other clean energy technologies. Similarly, the EPA's Clean Power Plan (CPP), introduced in 2015, aimed to reduce CO₂ emissions from power plants by setting state-specific targets and encouraging the adoption of cleaner energy sources. Although the CPP faced legal challenges and was ultimately replaced by the Affordable Clean Energy (ACE) rule under the Trump administration, it highlighted the potential of regulatory frameworks to drive decarbonization in the power sector (Sherlock, 2014; Celsa, and Xydis, 2023; Ayorinde, *et al.*, 2024).

Despite notable successes, the US regulatory framework for decarbonization faces several challenges and limitations. Political polarization and regulatory uncertainty have hindered the implementation of ambitious climate policies at the federal level, leading to inconsistent progress and delays in emissions reductions. Moreover, the influence of vested interests, including fossil fuel industries and lobbying groups, has sometimes undermined efforts to enact stronger regulations and transition towards cleaner energy sources. Additionally, the lack of a comprehensive national carbon pricing mechanism has limited the effectiveness of regulatory frameworks in incentivizing emissions reductions and fostering investment in low-carbon technologies (Burke, and Gambhir, 2022; Narassimhan, *et al.*, 2018).

In conclusion, the United States has a diverse and evolving regulatory landscape for decarbonization, characterized by a combination of federal, state, and local initiatives aimed at reducing emissions and promoting clean energy. While federal regulations such as the Clean Air Act provide a framework for addressing environmental challenges, state-level policies and incentives play a crucial role in driving emissions reductions and fostering innovation. Despite

successes, challenges such as political polarization, regulatory uncertainty, and vested interests pose significant obstacles to achieving ambitious climate goals. Moving forward, addressing these challenges will require concerted efforts from policymakers, stakeholders, and civil society to strengthen regulatory frameworks, promote renewable energy deployment, and accelerate the transition towards a low-carbon economy.

2.2 Regulatory frameworks in Nigeria

Nigeria, as Africa's most populous country and a major oil producer, faces unique challenges and opportunities in developing regulatory frameworks for decarbonization. The country's energy landscape is dominated by fossil fuels, particularly oil and natural gas, which account for the majority of its energy consumption and carbon emissions. Nigeria's carbon emissions profile is characterized by a combination of factors, including the extensive use of fossil fuels for electricity generation, industrial processes, transportation, and domestic energy needs (Egeruoh-Adindu, 2022; Dhali, *et al.*, 2023; Garba, *et al.*, 2022).

Despite its abundant natural resources, Nigeria's energy sector suffers from significant inefficiencies, infrastructure deficiencies, and environmental degradation. The reliance on fossil fuels has contributed to air and water pollution, deforestation, and loss of biodiversity, exacerbating environmental and public health concerns. Additionally, Nigeria's energy sector is vulnerable to the impacts of climate change, including extreme weather events, sea-level rise, and disruptions to agriculture and water resources.

In response to these challenges, Nigeria has taken steps to develop regulatory frameworks for decarbonization, with a focus on promoting renewable energy, energy efficiency, and sustainable development. The country has established institutions such as the Federal Ministry of Environment, the Nigerian Electricity Regulatory Commission (NERC), and the Energy Commission of Nigeria (ECN) to oversee environmental protection, energy regulation, and sustainable development initiatives. Additionally, Nigeria has adopted policies and laws such as the National Renewable Energy and Energy Efficiency Policy (NREEEP), the National Climate Change Policy (NCCP), and the Renewable Energy Master Plan (REMP) to promote decarbonization and transition to a low-carbon economy (Emodi, and Boo, 2015; Bulama, and Nchi, 2023; Ogbonna, *et al.*, 2023).

However, despite these efforts, Nigeria faces several challenges and limitations in implementing decarbonization policies. One major challenge is the lack of institutional capacity and regulatory enforcement mechanisms, which hinders effective implementation and compliance with environmental regulations. Weak governance, corruption, and political instability further undermine regulatory frameworks and deter investment in clean energy projects. Additionally, Nigeria's heavy reliance on oil revenues poses a barrier to decarbonization efforts, as vested interests in the fossil fuel industry may resist reforms that threaten their economic interests. Furthermore, inadequate infrastructure, limited access to finance, and socio-economic inequalities pose significant barriers to the widespread adoption of renewable energy and energy efficiency measures. The high upfront costs of clean energy technologies, coupled with limited financing options and technical capacity, hinder the deployment of renewable energy projects and energy efficiency initiatives. Moreover, socio-economic disparities,

including unequal access to electricity and clean cooking fuels, exacerbate energy poverty and hinder efforts to achieve universal energy access and sustainable development goals. Despite these challenges, Nigeria has significant opportunities for regulatory improvement and decarbonization. The country's abundant renewable energy resources, including solar, wind, hydroelectric, and biomass, offer vast potential for clean energy development and diversification of the energy mix. By harnessing these resources and investing in renewable energy infrastructure, Nigeria can reduce its dependence on fossil fuels, mitigate carbon emissions, and enhance energy security and resilience. Additionally, strengthening regulatory frameworks, improving governance, and enhancing stakeholder engagement can create an enabling environment for sustainable energy investment and promote inclusive and equitable development (Ragosa, and Warren, 2019; Jiang, and Martek, 2021).

In conclusion, Nigeria's energy landscape presents both challenges and opportunities for decarbonization. While the country faces significant barriers to regulatory implementation, including institutional weaknesses, vested interests, and socio-economic inequalities, it also has vast potential for clean energy development and sustainable growth. By addressing these challenges and leveraging its renewable energy resources, Nigeria can advance regulatory frameworks for decarbonization, promote inclusive and sustainable development, and contribute to global efforts to mitigate climate change.

2.3 Comparative Analysis: US vs. Nigeria regulatory frameworks

The regulatory frameworks for decarbonization in the United States and Nigeria represent contrasting approaches shaped by their unique socio-economic contexts, energy landscapes, and policy priorities. While the United States has a long history of environmental regulation and a diverse energy mix, Nigeria grapples with challenges such as energy poverty, infrastructure deficiencies, and heavy reliance on fossil fuels. Despite these differences, both countries share common goals of reducing carbon emissions, promoting sustainable development, and addressing the challenges of climate change. A comparative analysis of their regulatory frameworks offers valuable insights into the strengths, weaknesses, opportunities, and threats inherent in their respective approaches to decarbonization (Agbaitoro, 2023; Wesseling, *et al.*, 2017).

The United States has adopted a multifaceted approach to decarbonization regulation, characterized by a combination of federal, state, and local initiatives aimed at reducing emissions from various sectors such as energy, transportation, industry, and buildings. Federal regulations such as the Clean Air Act provide the Environmental Protection Agency (EPA) with the authority to regulate air pollutants, including greenhouse gases, while state-level policies and incentives complement federal efforts and allow for tailored approaches to address regional challenges and priorities. In contrast, Nigeria's regulatory framework for decarbonization is still in its nascent stages, with a focus on promoting renewable energy, energy efficiency, and sustainable development. The country has established institutions such as the Federal Ministry of Environment and the Nigerian Electricity Regulatory Commission (NERC) to oversee environmental protection and energy regulation, but

faces challenges such as institutional capacity, regulatory enforcement, and political instability (Ole, 2020).

Despite these differences, there are key similarities in the regulatory strategies adopted by both countries. Both the United States and Nigeria recognize the importance of promoting renewable energy and energy efficiency as key pillars of decarbonization. Both countries have adopted policies and laws to support renewable energy deployment, such as tax incentives, feed-in tariffs, and renewable energy targets. Additionally, both countries have set ambitious goals for reducing carbon emissions and enhancing resilience to climate change, albeit with varying levels of commitment and implementation (Andreasson, 2019; Dhali, *et al.*, 2023).

The United States' experience with decarbonization regulation offers several lessons applicable to Nigeria. One lesson is the importance of political leadership and bipartisan support for ambitious climate action. In the United States, successful decarbonization initiatives have often been driven by strong political leadership and consensus-building across party lines. Similarly, Nigeria can benefit from fostering political will and collaboration among policymakers, stakeholders, and civil society to advance decarbonization goals. Additionally, the United States' experience highlights the importance of stakeholder engagement, transparency, and accountability in the design and implementation of regulatory frameworks. Nigeria can learn from best practices in public participation, regulatory enforcement, and monitoring and evaluation to strengthen its institutional capacity and regulatory effectiveness (Chidolue, *et al.*, 2024; Adefemi, *et al.*, 2024).

Furthermore, there are significant opportunities for collaboration and knowledge exchange between the United States and Nigeria in advancing decarbonization efforts. Both countries can benefit from sharing best practices, lessons learned, and technical expertise in areas such as renewable energy development, energy efficiency, regulatory enforcement, and climate resilience. Collaborative initiatives such as joint research projects, capacity-building programs, and technology transfer agreements can facilitate knowledge exchange and promote innovation in clean energy technologies and regulatory approaches. Additionally, partnerships between government agencies, academic institutions, private sector actors, and international organizations can leverage resources and expertise to support decarbonization initiatives in both countries.

In conclusion, a comparative analysis of the regulatory frameworks for decarbonization in the United States and Nigeria offers valuable insights into the strengths, weaknesses, opportunities, and threats inherent in their respective approaches. While the two countries face different challenges and priorities, they share common goals of reducing carbon emissions, promoting sustainable development, and addressing the challenges of climate change. By learning from each other's experiences and collaborating on shared objectives, the United States and Nigeria can advance their decarbonization goals, accelerate the transition to a low-carbon economy, and contribute to global efforts to mitigate climate change.

2.4 Effectiveness metrics for regulatory frameworks

Effectiveness metrics for regulatory frameworks play a crucial role in assessing the success of policies aimed at decarbonization. These metrics provide valuable insights into the performance of regulatory interventions, helping

policymakers, stakeholders, and researchers evaluate progress towards emissions reduction targets, energy transition goals, and sustainable development objectives. By examining both quantitative and qualitative indicators, as well as real-world case studies, it becomes possible to gain a comprehensive understanding of the impact of regulations on decarbonization outcomes and identify opportunities for improvement (Bataille, *et al.*, 2016; Andrei, *et al.*, 2021).

Criteria for evaluating the success of regulatory frameworks encompass a range of factors, including environmental impact, economic efficiency, social equity, and regulatory effectiveness. Environmental impact metrics assess the extent to which regulations contribute to reductions in greenhouse gas emissions, air and water pollution, and other environmental indicators. Economic efficiency metrics examine the cost-effectiveness of regulatory interventions, considering factors such as the cost per ton of emissions reduced, the return on investment in clean energy technologies, and the overall economic benefits of decarbonization. Social equity metrics evaluate the distributional impacts of regulations, ensuring that vulnerable populations are not disproportionately burdened by the costs of compliance and that the benefits of decarbonization are equitably distributed across society. Regulatory effectiveness metrics assess the degree to which regulations achieve their intended objectives, including compliance rates, enforcement mechanisms, and the ability to adapt to changing circumstances.

Quantitative indicators of regulatory effectiveness include metrics such as emissions reductions, energy consumption, renewable energy deployment, and investment in clean energy technologies. These metrics provide tangible measures of progress towards decarbonization goals and can be tracked over time to assess the impact of regulatory interventions. For example, emissions reductions targets set by regulatory agencies can be compared against actual emissions data to determine the effectiveness of policies in reducing carbon emissions. Similarly, indicators such as the share of renewable energy in the electricity mix, energy intensity per unit of GDP, and energy efficiency improvements in buildings and transportation can provide insights into the success of regulations in promoting clean energy and energy efficiency (D'Arcangelo, *et al.*, 2022; Tsoi, *et al.*, 2021).

Qualitative indicators of regulatory effectiveness encompass a broader range of factors, including stakeholder engagement, policy coherence, regulatory enforcement, and innovation. These indicators offer valuable insights into the institutional, political, and social dimensions of regulatory frameworks, helping to identify barriers to implementation and opportunities for improvement. For example, qualitative assessments of stakeholder engagement processes can gauge the level of public participation, transparency, and accountability in the design and implementation of regulations. Similarly, assessments of regulatory coherence can evaluate the consistency, coherence, and compatibility of regulatory frameworks across different sectors and levels of government.

Case studies illustrating the impact of regulations on decarbonization outcomes provide valuable real-world examples of regulatory effectiveness in action. These case studies showcase successful regulatory interventions, highlight best practices, and identify lessons learned from experiences in different countries, regions, and sectors. For

example, case studies of renewable energy deployment initiatives can demonstrate the effectiveness of feed-in tariffs, renewable portfolio standards, and other policy instruments in driving investment in clean energy technologies. Similarly, case studies of energy efficiency programs can highlight the role of regulations, incentives, and public-private partnerships in reducing energy consumption and greenhouse gas emissions in buildings, industry, and transportation. In conclusion, effectiveness metrics for regulatory frameworks are essential tools for evaluating the success of policies aimed at decarbonization. By considering a range of criteria, including environmental impact, economic efficiency, social equity, and regulatory effectiveness, policymakers, stakeholders, and researchers can gain a comprehensive understanding of the impact of regulations on decarbonization outcomes. By examining both quantitative and qualitative indicators, as well as real-world case studies, it becomes possible to identify opportunities for improvement, enhance regulatory effectiveness, and accelerate progress towards a low-carbon future.

2.5 Stakeholder perspectives and engagement

Stakeholder perspectives and engagement play a vital role in shaping and implementing regulatory frameworks for decarbonization. Stakeholders, including governments, businesses, civil society organizations, communities, and individuals, bring diverse perspectives, interests, and expertise to the policymaking process, influencing the design, implementation, and outcomes of regulatory interventions. By actively engaging stakeholders throughout the policy cycle, policymakers can build consensus, foster trust, and enhance the legitimacy and effectiveness of regulatory frameworks (Lange, and Cummins, 2021).

The role of stakeholders in shaping and implementing regulatory frameworks is multifaceted and dynamic. Stakeholders contribute to the development of regulations by providing input, expertise, and feedback during the policy formulation process. For example, industry stakeholders may offer insights into technological feasibility, economic impacts, and market dynamics, helping policymakers design regulations that are practical, cost-effective, and conducive to innovation. Similarly, civil society organizations and advocacy groups may advocate for stronger regulations, highlight social and environmental concerns, and mobilize public support for policy change. Once regulations are enacted, stakeholders play a critical role in implementation, compliance, and enforcement, collaborating with regulators to ensure effective implementation and address challenges as they arise (Linton, *et al.*, 2020).

Public participation and feedback mechanisms are essential for ensuring that regulatory frameworks reflect the needs, priorities, and values of affected stakeholders. Meaningful engagement with stakeholders promotes transparency, accountability, and democratic decision-making, enabling policymakers to build trust, legitimacy, and public support for regulatory interventions. Public participation mechanisms such as public hearings, consultations, and comment periods provide opportunities for stakeholders to voice their concerns, provide input, and participate in the decision-making process. Additionally, feedback mechanisms such as stakeholder surveys, monitoring and evaluation processes, and regulatory impact assessments allow policymakers to assess the effectiveness of regulations, identify unintended consequences, and make informed adjustments as needed.

However, stakeholder engagement also presents challenges and complexities that policymakers must navigate to ensure effective and inclusive participation. One challenge is ensuring that the voices of marginalized and vulnerable groups are heard and represented in the policymaking process. Historically, certain stakeholders, such as low-income communities, indigenous peoples, and minority groups, have been disproportionately impacted by environmental degradation and regulatory decisions, yet their perspectives and interests are often overlooked or marginalized in decision-making processes. Overcoming this challenge requires proactive efforts to engage with diverse stakeholders, address power imbalances, and promote inclusive participation through targeted outreach, capacity-building, and representation mechanisms. Another challenge is managing conflicts of interest and balancing competing stakeholder priorities. Stakeholders may have divergent interests, values, and objectives, leading to disagreements, tensions, and conflicts in the policymaking process. Resolving conflicts and reaching consensus requires effective communication, negotiation, and mediation skills, as well as mechanisms for conflict resolution and dispute resolution. Additionally, policymakers must guard against undue influence from vested interests, such as industry lobbyists, and ensure that regulatory decisions are based on evidence, science, and the public interest rather than narrow sectoral interests (Nasiritousi, and Grimm, 2022; D'Arcangelo, *et al.*, 2022).

Despite these challenges, there are best practices in stakeholder engagement that can help policymakers navigate the complexities of the policymaking process and foster meaningful dialogue, collaboration, and partnership with stakeholders. One best practice is to adopt a participatory and inclusive approach to policymaking, involving stakeholders early and often in the decision-making process and providing multiple avenues for input and feedback. Additionally, policymakers should prioritize transparency, accountability, and openness in their interactions with stakeholders, providing clear information, rationale, and justifications for regulatory decisions and outcomes. Moreover, fostering trust and building relationships with stakeholders requires genuine engagement, active listening, and responsiveness to stakeholder concerns and priorities.

In conclusion, stakeholder perspectives and engagement are essential elements of effective regulatory frameworks for decarbonization. By actively involving stakeholders throughout the policy cycle, policymakers can build consensus, foster trust, and enhance the legitimacy and effectiveness of regulatory interventions. Public participation and feedback mechanisms promote transparency, accountability, and democratic decision-making, ensuring that regulations reflect the needs, priorities, and values of affected stakeholders. While stakeholder engagement presents challenges and complexities, best practices such as inclusivity, transparency, and responsiveness can help policymakers navigate the complexities of the policymaking process and foster meaningful dialogue, collaboration, and partnership with stakeholders.

2.6 Adaptive governance and policy flexibility

Adaptive governance and policy flexibility are crucial components of effective regulatory frameworks for decarbonization, enabling policymakers to respond to evolving challenges, uncertainties, and opportunities in a

rapidly changing world. As the impacts of climate change become more pronounced and the need for decarbonization becomes increasingly urgent, adaptive governance approaches are essential for ensuring that regulatory frameworks remain relevant, responsive, and resilient in the face of complex and dynamic environmental, social, and economic systems. Adaptive governance refers to the ability of policymakers, stakeholders, and institutions to learn, innovate, and adapt in response to changing circumstances, feedback, and new information. It emphasizes flexibility, experimentation, and collaboration as key principles for navigating uncertainty and complexity in policymaking processes. Adaptive governance approaches recognize that decarbonization is a dynamic and iterative process, requiring continuous monitoring, evaluation, and adjustment of policies, strategies, and interventions to achieve desired outcomes and address emerging challenges (Cassotta, 2016). The importance of adaptive governance in responding to evolving decarbonization challenges cannot be overstated. Climate change is characterized by uncertainty, non-linearity, and systemic risks, making it difficult to predict future impacts, identify optimal solutions, and achieve consensus among stakeholders. Adaptive governance approaches offer a way to navigate these complexities by embracing uncertainty, learning from experience, and incorporating new knowledge and insights into decision-making processes. By fostering flexibility, resilience, and adaptive capacity, adaptive governance enables policymakers to anticipate, mitigate, and adapt to the impacts of climate change, while also promoting innovation, experimentation, and collaboration in the pursuit of sustainable development goals (Mathy, *et al.*, 2016; Low, and Boettcher, 2020). Flexibility mechanisms within regulatory frameworks are essential tools for enabling adaptive governance and promoting policy flexibility in response to changing circumstances. These mechanisms allow policymakers to adjust regulations, policies, and incentives in real-time, based on feedback, evaluation, and stakeholder input. Examples of flexibility mechanisms include sunset clauses, which automatically expire regulations after a certain period unless renewed, allowing policymakers to review and update regulations as needed; regulatory sandboxes, which provide safe spaces for testing new regulatory approaches and technologies in controlled environments before scaling up; and adaptive management frameworks, which incorporate monitoring, evaluation, and feedback loops into regulatory decision-making processes to facilitate learning, adaptation, and continuous improvement. Case studies highlighting successful adaptation to changing circumstances provide valuable insights into the practical application of adaptive governance and policy flexibility in the context of decarbonization. For example, the European Union's Emissions Trading System (EU ETS) has evolved over time to address challenges such as carbon leakage, market volatility, and competitiveness concerns, through mechanisms such as the Market Stability Reserve (MSR) and the Carbon Border Adjustment Mechanism (CBAM). These adaptive governance approaches enable the EU to adjust the allocation, pricing, and regulation of emissions allowances in response to changing market conditions and policy objectives, while also promoting innovation, investment, and decarbonization across sectors. Similarly, the implementation of renewable energy policies and incentives in countries such as Germany, Denmark, and China demonstrates the

importance of adaptive governance and policy flexibility in driving the transition to clean energy. These countries have adopted flexible approaches to renewable energy deployment, including feed-in tariffs, renewable portfolio standards, and auction mechanisms, which allow for adjustments based on market dynamics, technological advancements, and policy goals. By embracing adaptive governance principles and fostering policy flexibility, these countries have been able to achieve significant reductions in carbon emissions, increase renewable energy deployment, and promote economic growth and innovation in clean energy sectors (Verbruggen, *et al.*, 2019; Lagouvardou, and Psarafitis, 2022).

In conclusion, adaptive governance and policy flexibility are essential elements of effective regulatory frameworks for decarbonization, enabling policymakers to respond to evolving challenges, uncertainties, and opportunities in a rapidly changing world. By embracing flexibility, experimentation, and collaboration, adaptive governance approaches promote resilience, innovation, and sustainability, while also ensuring that regulatory frameworks remain relevant, responsive, and effective in achieving decarbonization goals. Case studies highlighting successful adaptation to changing circumstances provide valuable insights into the practical application of adaptive governance and policy flexibility in driving the transition to a low-carbon future, offering lessons and inspiration for policymakers, stakeholders, and researchers around the world.

2.7 Regulatory innovation and emerging technologies

Regulatory innovation and the adoption of emerging technologies are essential for addressing the complex challenges of decarbonization and driving sustainable development. As countries worldwide strive to reduce greenhouse gas emissions and transition to low-carbon economies, innovative regulatory approaches and the integration of cutting-edge technologies play a pivotal role in shaping the regulatory landscape and unlocking opportunities for transformative change. Both the United States and Nigeria are exploring innovative regulatory approaches to accelerate decarbonization efforts, albeit within their unique socio-economic contexts and energy landscapes (Arent, *et al.*, 2022; Labanca, *et al.*, 2020).

In the United States, regulatory innovation has been a cornerstone of environmental policy for decades, with federal, state, and local governments adopting a range of innovative approaches to address environmental challenges, including climate change. One example is the adoption of market-based mechanisms such as emissions trading systems, which allow polluters to buy and sell emissions allowances, thereby creating economic incentives for emissions reductions. The Regional Greenhouse Gas Initiative (RGGI) in the northeastern United States and California's cap-and-trade program are notable examples of emissions trading systems that have successfully reduced greenhouse gas emissions while promoting economic growth and innovation (Nadel, and Kubes, 2019; Raymond, 2019). Similarly, Nigeria is exploring innovative regulatory approaches to decarbonization, leveraging emerging technologies and partnerships to address energy poverty, promote clean energy access, and accelerate sustainable development. The country has adopted policies and initiatives such as the National Renewable Energy and

Energy Efficiency Policy (NREEEP) and the Renewable Energy Master Plan (REMP) to promote renewable energy deployment and energy efficiency improvements. Additionally, Nigeria is exploring innovative financing mechanisms such as green bonds and climate funds to mobilize investment in clean energy projects and infrastructure.

The role of emerging technologies in driving regulatory innovation cannot be overstated. From renewable energy technologies such as solar, wind, and hydroelectric power to energy storage, smart grids, and electric vehicles, emerging technologies offer transformative solutions for decarbonization and sustainable development. These technologies enable policymakers to overcome traditional barriers to clean energy deployment, such as intermittency, reliability, and affordability, while also unlocking new opportunities for innovation, job creation, and economic growth. For example, advancements in renewable energy technologies have dramatically reduced the cost of solar and wind power, making them increasingly competitive with fossil fuels in many parts of the world. Similarly, energy storage technologies such as batteries, pumped hydro, and thermal energy storage are enabling the integration of renewable energy into the grid, providing flexibility and stability to support the transition to a low-carbon energy system. Additionally, smart grid technologies, demand response programs, and energy management systems are empowering consumers to optimize their energy use, reduce costs, and contribute to grid stability and reliability.

However, the adoption of emerging technologies also presents regulatory challenges and opportunities that must be addressed to realize their full potential for decarbonization. One challenge is ensuring that regulatory frameworks keep pace with technological advancements and innovation, allowing for flexibility, adaptation, and experimentation. Regulatory frameworks must be agile, adaptive, and forward-thinking, enabling regulators to anticipate and respond to emerging risks, uncertainties, and opportunities in a rapidly changing technological landscape. Another challenge is balancing innovation with safety, security, and ethical considerations. As emerging technologies such as artificial intelligence, blockchain, and Internet of Things (IoT) become increasingly integrated into energy systems, regulators must ensure that appropriate safeguards are in place to protect against potential risks such as cybersecurity threats, data privacy breaches, and unintended consequences. Additionally, regulators must address ethical and social implications of emerging technologies, such as equity, accessibility, and environmental justice, to ensure that the benefits of innovation are equitably distributed across society (Rissman, *et al.*, 2020; Di Silvestre, *et al.*, 2018).

Despite these challenges, emerging technologies offer unprecedented opportunities for regulatory innovation and decarbonization. By embracing innovation, collaboration, and partnership, regulators can harness the power of emerging technologies to accelerate the transition to a low-carbon future, promote sustainable development, and build resilience to climate change. From smart grids and electric vehicles to renewable energy microgrids and distributed energy resources, emerging technologies offer transformative solutions that have the potential to revolutionize energy systems and unlock new opportunities for economic growth, job creation, and environmental stewardship. As countries worldwide strive to achieve their decarbonization goals and

build a more sustainable future, regulatory innovation and the adoption of emerging technologies will play a central role in shaping the regulatory landscape and driving progress towards a cleaner, more resilient, and prosperous world.

2.8 Recommendations for enhancing regulatory frameworks

Enhancing regulatory frameworks for decarbonization requires a multifaceted approach that addresses the unique challenges and opportunities faced by different countries and regions. In the United States, policymakers can take several policy recommendations to improve decarbonization regulation. Firstly, there should be a concerted effort to strengthen federal regulations targeting emissions from key sectors such as energy, transportation, industry, and buildings. This could involve revisiting and updating existing regulations such as the Clean Air Act to incorporate more ambitious emissions reduction targets and promote the adoption of clean energy technologies. Additionally, the United States can benefit from implementing comprehensive carbon pricing mechanisms such as a carbon tax or cap-and-trade program, which provide economic incentives for emissions reductions while generating revenue for investment in clean energy and climate resilience. Furthermore, there is a need for increased federal support for research, development, and deployment of clean energy technologies, as well as incentives for private sector investment in renewable energy and energy efficiency projects.

In Nigeria, strengthening regulatory frameworks for decarbonization requires a focus on promoting renewable energy deployment, energy efficiency improvements, and sustainable development. Policymakers can consider implementing stronger incentives for renewable energy adoption, such as feed-in tariffs, tax credits, and grants, to stimulate investment in clean energy projects and infrastructure. Additionally, there is a need for regulatory reforms to streamline permitting processes, reduce bureaucratic hurdles, and improve access to financing for renewable energy projects, particularly in rural and underserved areas.

Moreover, Nigeria can benefit from enhancing regulatory enforcement mechanisms and building institutional capacity to monitor and enforce compliance with environmental regulations. This could involve strengthening the capacity of regulatory agencies such as the Nigerian Electricity Regulatory Commission (NERC) and the Federal Ministry of Environment to oversee environmental protection, energy regulation, and sustainable development initiatives. Additionally, there is a need for greater collaboration and coordination among government agencies, private sector actors, civil society organizations, and international partners to address regulatory gaps, overcome barriers to implementation, and achieve decarbonization goals.

Fostering international cooperation and knowledge sharing is critical for accelerating decarbonization efforts and building resilient, low-carbon economies worldwide. Countries can collaborate on joint research projects, capacity-building programs, and technology transfer agreements to share best practices, lessons learned, and innovative solutions for addressing common challenges. International forums such as the United Nations Framework Convention on Climate Change (UNFCCC), the International Renewable Energy Agency (IRENA), and the Clean Energy Ministerial (CEM)

provide platforms for countries to exchange ideas, share experiences, and forge partnerships for advancing decarbonization goals.

In conclusion, enhancing regulatory frameworks for decarbonization requires a coordinated and collaborative effort by policymakers, stakeholders, and researchers at the national, regional, and international levels. By implementing policy recommendations to improve decarbonization regulation in the United States and strengthening regulatory frameworks in Nigeria, countries can accelerate progress towards a low-carbon future, promote sustainable development, and build resilience to climate change. Moreover, fostering international cooperation and knowledge sharing is essential for addressing global challenges, leveraging resources, and unlocking opportunities for transformative change. Policymakers, stakeholders, and researchers must seize this moment to take bold action and drive the transition to a cleaner, more sustainable, and prosperous world.

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