Energy policies and regulatory pathways for a sustainable transition: a global review

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20.1 Introduction

The global energy sector is undergoing a significant transformation driven by the urgent need to address climate change, rapid technological advancements and shifting economic priorities (Berahab, 2025; IRENA, 2023). As global energy demand continues to grow, governments and industries face increasing pressure to transition toward cleaner, more resilient, and sustainable energy systems (IRENA, 2023). However, the continued dependence on fossil fuels, together with regulatory uncertainties and economic constraints, presents majorchallenges to achieving a sustianable energy transition (Ahuja et al., 2019; Gunnarsdottir et al., 2021; Saleh and Hassan, 2024).

Thus, establishing a well-structured policy framework is fundamental to addressing the challenges associated with excessive dependence fossil fuels (Debrah et al., 2020; Nyasapoh et al., 2022). These challenges often stem from regulatory uncertainties and economic constraints, as as robust and coherent policies play a crucial role in accelerating the adoption of sustainable energy technologies (Mohammadi et al., 2023). Strategic policy instruments are essential for creating an enabling environment for renewable energy (Nyasapoh et al., 2025; Nyasapoh et al., 2022; Strielkowski et al., 2021; UCS, 2017), nuclear power (Brook et al., 2014; Debrah et al., 2020; IAEA, 2017), and clean gas while also reducing the entrenched dominance of high-emission energy sources (Adelekan et al., 2024; Brussels, 2022; Metaxas, 2024).

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Thus, a sustainable energy future requires an integrated policy mix that promotes investment in clean technologies and addressesthe socioeconomic and environmental impacts associated with energy reforms (Adulugba, 2021; IRENA, 2023; Li and Taeihagh, 2020).

Despite global commitments to carbon neutrality, integrating diverse clean energy technologies remains a challenge. Renewable energy sources such as solar and wind have considerable potential, but their intermittent nature necessitates complementary solutions (Nyasapoh et al., 2023; Nyasapoh et al., 2024), including battery storage, smart grids, and hybrid systems (Adelekan et al., 2024; Cosgrove et al., 2023). Hydropower continues to be a major contributor to global electricity generation, accounting for a substantial share of global output (GlobalData, 2024). While hydropower projects provide low-carbon electricity with high efficiency and reliability, they also present environmental trade-offs, such as altering river ecosystems and displacing local communities (Kabo-Bah and Diji, 2018; Statista, 2023). As a result, effective policy measures, including comprehensive environmental impact assessments and integrated watershed management, are necessary to balance hydropower development with ecological sustainability. Additionally, the sustainable expansion of renewable energy infrastructure requires careful consideration of unintended environmental and social impacts, reinforcing the need for well-formulated policies that align with sustainable development objectives (Al-Shetwi et al., 2024; Hamilton, 2014). Clean gas technologies, including hydrogen and carbon capture and storage (CCS), have gained attention as transitional solutions, yet their commercial viability and infrastructure readiness remain significant barriers (Metaxas, 2024). Nuclear power, particularly small modular reactors, presents a viable low-carbon alternative with stable baseload capacity, especially for developing countries (Nyasapoh et al., 2024a; Nyasapoh, et al., 2024b). However, safety concerns, waste disposal issues, and high capital costs hinder widespread adoption of nuclear technology for electricity generation (US Department of Energy, 2024).

The transition to a sustainable energy system involves complex policy, technological, and economic challenges (Mohammadi et al., 2023). Althoughclean energy technologies have advanced, the uneven integration of renewables, nuclear, and clean gas across regions is driven byregulatory uncertainties, infrastructure gaps, and financial limitations (Berahab, 2025; IEA, 2009; Saleh and Hassan, 2024). Continued dependence on fossil fuels further undermines global decarbonisation efforts (IEA, 2024a). A comprehensive evaluation of energy policies is therefore essential to identifying effective approaches and developing strategies that support sustainable energy transitions.

This study examines global energy policies and regulatory frameworks to assess their effectiveness in promoting sustainable energy transitions. It traces the evolution of energy policies and their influence on clean energy adoption, highlights key policy instruments that support the integration of renewables, nuclear, and clean gas, evaluates the challenges and opportunities within existing regulatory frameworks, and outlines policy recommendations to enhance sustainability and energy security across divrse geopolitical contexts.

Using a systematic literature review approach, the study synthesises peer-reviewed articles, policy reports, and publications from international energy agencies. Thematic analysis is applied to categorise policy trends, regulatory barriers, and technological developments. Comparative case studies from major economies, including the United States, the European Union, China, and Africa, provide empirical insights into the effectiveness and implementation challenges of different energy policy models. Data sources include reports from the International Renewable Energy Agency (IRENA), the International Energy Agency (IEA), and national energy policy frameworks.

This study provides a foundation for policy-driven solutions that bridge the gap between rising energy demand and sustainability goals, ultimately supporting a cleaner, and more resilient global energy system. By offering a comprehensive assessment of policy instruments and regulatory challenges, the study further contributes to ongoing discussions on global energy transitions. It is particularly relevant for policymakers, energy analysts, and researchers seeking to align energy policies with sustainable development goalsand international climate commitments. It also offers strategic guidance for developing countries, especially in Africa, to accelerate clean energy adoption and strengthen economic growth through sustainable energy investments.

20.2 Methodology

This study applied a qualitative research approach structured into five interconnected stages. Fig. 20.1 presents the methodological framework for the study. Each step is connected by a downward arrow, indicating the flow from one step to the next for the entire study.

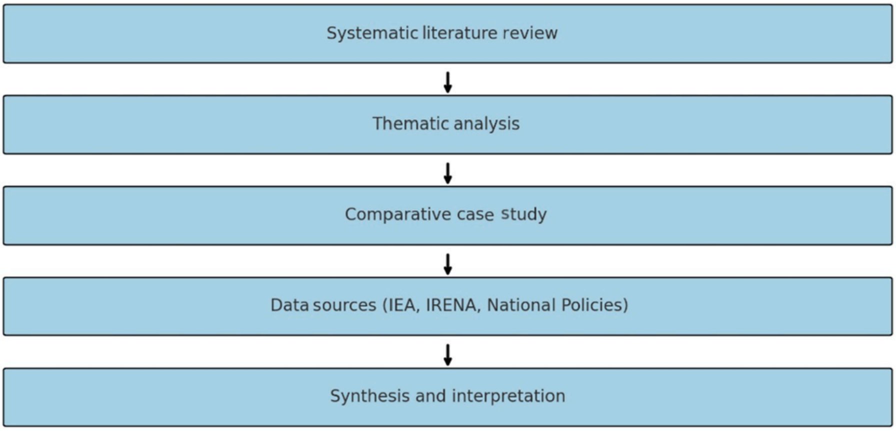

Figure 20.1 Methodological framework (Author draft).

20.2.1 Systematic literature review

The investigation began with a rigorous review of scholarly articles, international energy reports, and official policy documents. Selection criteria focused on recent and high-impact publications related to global energy transitions, regulatory reforms, and sustainability strategies. Databases such as Scopus, Web of Science, and repositories from the IEA and IRENA were key sources.

20.2.2 Thematic analysis

Extracted content was organised into recurring themes such as policy evolution, regulatory challenges, clean energy integration, and technological policy alignment. This analytical process enabled the identification of policy patterns and priority areas across different regions.

20.2.3 Comparative case study

To strengthen contextual relevance, a comparative lens was applied to analyse how selected countries or continents, such as the United States, China, members of the European Union, and nations in Africa, have tailored their energy policies. This comparative view revealed differences in policy architecture, implementation strategies, and regulatory flexibility.

20.2.4 Data sources

The study relied on credible institutional reports and policy documentation from leading organisations, including national energy policies:

- International Renewable Energy Agency
- International Energy Agency
- Regional and national energy policy frameworks, strategic documents, and development plans

Together, these sources provided strong triangulation and enhanced the reliability and validity of the insights that informed the study's analysis and discussions.

20.2.5 Synthesis and interpretation

Finally, the study integrated the findings to draw meaningful conclusions on policy effectiveness, regulatory bottlenecks, and pathways for sustainable energy transitions. This interpretive synthesis serves to inform actionable recommendations for policy-makers and stakeholders.

20.3 Historical context of energy policies

The historical evolution of energy policies has been intricately linked to global economic growth, geopolitical shifts, and environmental concerns (Hafner and Tagliapietra, 2020; Scholten, 2024). Initially, energy policies were primarily designed to secure reliable fossil fuel supplies, ensuring industrial expansion and economic stability (Adelekan et al., 2024). However, as global awareness of climate change and resource depletion intensified, policy directions shifted towards sustainability and renewable energy integration (Falcone, 2023). The establishment of the IEA in 1974 marked a pivotal moment, driven by the need to enhance energy security following the oil crisis (IEA, 1974). Decades later, international agreements such as the Kyoto Protocol (1997) and the Paris Agreement (2015) reinforced global commitments to emission reductions and sustainable energy transitions (UNFCCC, 2025).

Inevitably, international organisations have played a crucial role in shaping energy policies by providing regulatory frameworks and policy guidelines. The United Nations Framework Convention on Climate Change (UNFCCC) has facilitated multilateral climate action, leading to mechanisms that directly or indirectly support sustainable energy policies (Kuh, 2018; United Nations, 1992). The IRENA has similarly supported governments in formulating policies that promote renewable energy adoption, while the Energy Charter Treaty has provided governance structures for energy-related trade and investment protections (Energy Charter Secretariat, 1998). These frameworks have helped countries navigate the complexities of transitioning from fossil fuel dependency to cleaner energy sources.

Energy policy encompasses various activities, including energy resource extraction, production, distribution, and consumption (Mohammadi et al., 2023). In addition to large-scale energy production, decentralised energy generation has gained significance, with small-scale producers, such as rooftop solar PV system owners and energy communities, playing a growing role in energy markets. Their inclusion in energy policy discussions necessitates regulatory adaptations to support grid integration, net metering, and fair market participation (Aalto et al., 2020).

National energy policies are shaped by various factors, including resource availability, economic conditions, technological advancements, and government priorities (Falcone, 2023). A key milestone in international governance was the adoption of the UNFCCC in 1992, which laid the foundation for legally binding commitments aimed at reducing global carbon emissions (United Nations, 1992). These policy developments have influenced national energy strategies, guiding efforts to balance energy security with sustainability.

Fig. 20.2 illustrates the historical trajectory of global energy policies, highlighting key international milestones that have shaped the transition toward sustainable energy. The evolution of energy consumption, as depicted in the figure, underscores the shift from traditional biomass (pre-1800) to coal (industrial revolution), oil (20th century), and the increasing dominance of renewable energy sources in the 21st century (Smil, 2017; World Economic Forum, 2022).

The timelines as projected above align with critical policy interventions such as:

- The establishment of the IEA in 1974 in response to the global oil crisis emphasised the need for coordinated energy security measures (IEA, 1974).

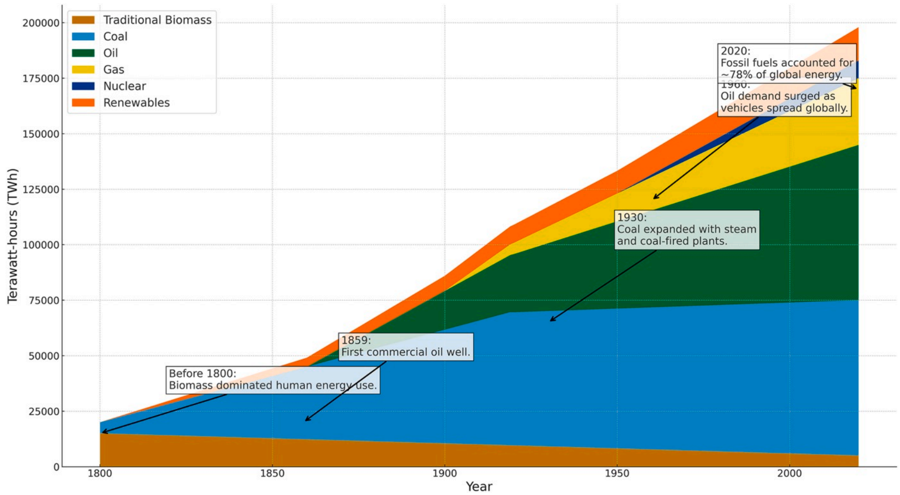

Figure 20.2 Historical trajectory of global energy policies (World Economic Forum, 2022).

- The adoption of international climate agreements, including the Kyoto Protocol (1997) and the Paris Agreement (2015), set global targets for carbon emission reductions (UNFCCC, 2025).
- The implementation of renewable energy mandates and sustainability-driven policies in the 21st century to accelerating the transition toward cleaner energy sources (Al-Shetwi et al., 2024; Yergin, 2020).

Beyond formal policy interventions, geopolitical events, economic crises, and environmental disasters have significantly influenced energy policy development. The 1973 Oil Crisis, triggered by an Organisation of the Petroleum Exporting Countries embargo, exposed the risks of excessive dependence on fossil fuels and prompted industrialised nations to prioritise energy diversification and efficiency (D'Augusta et al., 2024; Jefferson, 2015). Countries like Japan and Germany responded by introducing aggressive energy efficiency policies and investing in alternative energy sources, laying the groundwork for modern renewable energy initiatives (Goldthau and Westphal, 2019).

Moreover, economic downturns have also shaped energy policy direction. For instance, the 2008 Global Financial Crisis led to a temporary decline in renewable energy investments as governments prioritised economic recovery over climate action (IEA, 2009). However, subsequent stimulus packages in major economies, such as the United States and the European Union, included significant funding for clean energy projects, reinforcing the long-term shift toward sustainability (IEA, 2020a).

Besides, environmental disasters have further driven transformative energy policy shifts. The 2011 Fukushima nuclear disaster led Japan to reassess its nuclear strategy, resulting in a pivot toward increased renewable energy adoption (Ghalehteimouri, 2024). Similarly, the 2010 Deepwater Horizon oil spill in the United States triggered stricter environmental regulations on offshore drilling and bolstered the case for cleaner energy alternatives (D'Augusta et al., 2024). These crises underscore the necessity of resilient and adaptive policy frameworks to mitigate risks and ensure energy security and sustainability.

As global energy systems continue to evolve, future energy policies will likely be shaped by technological advancements, enhanced energy efficiency, and accelerated clean energy transitions (Rapier, 2025). Hence, the need for comprehensive policies that integrate sustainability, economic growth, and energy security remains paramount. Ensuring that national and global energy strategies align with climate objectives and long-term development goals will be crucial in achieving a balanced, secure, and sustainable energy future.

20.4 Current global energy policies

The formulation and implementation of energy policies vary significantly across the world, reflecting differences in economic priorities, resource availability, and political ideologies (Jefferson, 2015). While some nations emphasise market-driven approaches to energy governance, others rely on state-controlled mechanisms to regulate production, distribution, and consumption (Kaswan, 2018; Michoud and Hafner, 2021). Energy policies are fundamental to the functioning of modern economies, influencing critical sectors such as housing, transportation, industry, and agriculture (Kaswan, 2018). Given that the energy sector is the largest contributor to global greenhouse gas (GHG) emissions, energy policies play a decisive role in climate change mitigation efforts to ensure sustainable development (Hamilton, 2014).

As a result, the interconnection between climate and energy policies underscores the necessity for coordinated global action. However, despite the urgency of climate change, many governments struggle to fully integrate environmental concerns into their energy policies (Grant et al., 2022). A key challenge remains the decarbonization of the transportation sector, which is still largely dependent on fossil fuels (Kaswan, 2018). Inevitably, technological advancements, including the rise of electric vehicles and vehicle-to-grid (V2G) systems, offer promising solutions to reduce emissions and enhance grid stability (Al-Shetwi et al., 2024).

20.4.1 National and continental energy policies and transition paths

Countries have adopted varied strategies for energy transition, shaped by their economic priorities, policy frameworks, and resource availability. The following highlights key national approaches to current energy policies:

20.4.1.1 Africa

The Mission 300 initiative, led by the World Bank Group, the African Development Bank Group, and the Sustainable Energy for All (SE4ALL) initiative, aims to expand electricity access to 300 million people in Africa by 2030. This initiative focuses on infrastructure improvements, policy reforms, and private sector investments to enhance the continent's energy sector (UN Sustainable Development Group, 2025). Many African nations, including Nigeria, Ghana, Ethiopia, Kenya, South Africa, and Morocco, are actively implementing renewable energy policies to achieve universal electricity access (African Development Bank Group, 2023).

20.4.1.2 Australia

Australia promotes energy efficiency through the Energy Savings Scheme, which provides financial incentives for households to adopt energy-efficient appliances, reducing both emissions and electricity consumption (Australia Government, 2024; NSW Government, 2024).

20.4.1.3 China

China's energy transition is characterised by aggressive renewable energy expansion through state-led initiatives (Hilton, 2024). By setting ambitious targets, providing subsidies, and fostering domestic technological advancements, China has emerged as a global leader in clean energy deployment (Committee on US-China Cooperation, 2010; Zhou, 2015).

20.4.1.4 Denmark

Denmark's REPowerEU Initiative prioritises replacing oil burners and gas-based heating systems with renewable alternatives such as heat pumps. This policy is central to Denmark's strategy for reducing fossil fuel dependence and accelerating the green energy transition (The Danish Government, 2023).

20.4.1.5 European Union

The European Union has set a legally binding target to achieve carbon neutrality by 2050, enforced through the European Green Deal and European Climate Law (European Commission, 2021b). These policies mandate significant reductions in GHG emissions, promote renewable energy adoption, and enhance energy efficiency across all sectors (European Parliament, 2024).

20.4.1.6 France

France encourages green industrial investments through tax incentives, particularly for heat pumps. The Tax Credit for Investment in Green Industry (C3IV), effective from January 2024, aims to accelerate the development of decarbonization technologies and strengthen France's clean energy sector (ABGi, 2025).

20.4.1.7 Germany

Germany finances its decarbonization initiatives through the Special Climate and Transformation Fund (Klima- und Transformationsfonds), supporting renewable energy projects, energy efficiency upgrades, and electric mobility advancements (Amelang et al., 2025; Erbach, 2024; IEA, 2024b).

20.4.1.8 Japan

Japan enhances energy efficiency through stricter building regulations, including the Building Energy Efficiency Act, which mandates high-performance ventilation systems for new constructions and retrofits. This aligns with the country's broader goal of reducing carbon emissions and achieving carbon neutrality (ABGi, 2025; IEA, 2021).

20.4.1.9 South Korea

South Korea's Rural 100% Renewable Energy (RE100) Demonstration Projects aim to transition 570 TWh of electricity per year to renewable sources by 2050, surpassing the country's current total electricity consumption (RE100, 2025). Additionally, its Renewable Energy 3020 Plan seeks to generate 20% of electricity from renewables by 2030, with a gradual phase-out of coal and nuclear power, alongside hydrogen energy advancements under the Green New Deal (IEA, 2020b).

20.4.1.10 United States

The United States employs a combination of federal and state policies to drive renewable energy adoption and emissions reduction (Burtraw and Palmer, 2015). Its 2035 Nationally Determined Contribution is designed to be both ambitious and practical, leveraging existing policies, investments, and regulatory frameworks while accelerating decarbonization. The transition relies on coordinated efforts across multiple stakeholders, including government agencies, private enterprises, and civil society (United States of America, 2024).

Table 20.1 provides a comparative analysis of energy policy approaches across major economies. It highlights key differences in renewable energy targets, regulatory strategies, and policy instruments. For instance, while the United States prioritises market-driven incentives, the European Union enforces a robust regulatory framework, and China pursues an interventionist model with substantial state-led investments in clean energy.

As nations continue their energy transitions, success will depend on the ability to integrate technological advancements, regulatory mechanisms, and economic incentives into coherent policy frameworks. By fostering innovation and cross-sector collaboration, global energy policies can drive sustainability while ensuring energy security and economic resilience for the needed global and national developments.

20.4.2 Key pathways to a sustainable energy future

Despite the varying approaches countries take toward energy transition, global energy policies generally focus on three key areas as pathways to a sustainable energy future. The three paths include climate change commitments, sustainable energy development, and the broader energy transition.

Table 20.1 Comparative analysis of energy policy approaches across major economies.

Country	Policy approach	Sustainable and renewable energy target	Key regulations
The United States	Market-driven incentives (tax credits, subsidies)	A bill to consolidate more than 40% of energy incentives into three emissions-based incentives to create jobs, combat the climate crisis, and achieve 50% emission reductions by 2030.	United States Senate Committee on Finance (Schapitl, 2021).
The Europe-an Union	Strong regulatory frameworks (carbon pricing, mandates)	Net-zero emissions by 2050.	Delivering the European Green Deal, on the path to a climate-neutral Europe by 2050 (European Commission, 2021a, 2023).
China	State-led investments and mandates.	Increase the share of non-fossil fuels in primary energy consumption to around 20%, and also peak their overall GHG emissions by 2030.	China's Future Generation 2.0 (Chandler et al., 2015).
Japan	Technology-driven efficiency policies	Achieving the global goal of net-zero by 2050: tripling renewable energy capacity globally and doubling the global average annual rate of energy efficiency improvements by 2030, and reducing greenhouse gas emissions by 46% by 2030 compared to 2013 levels, with a further aspirational goal of a 50% reduction. 2030.	Japan's Initiatives for Achieving the Common Goal of Net Zero by 2050 (The Government of Japan, 2024). Japan's initiative toward net-zero GHG emissions by 2050 (Japan UNFCC, 2025; Ministry of Foreign Affairs of Japan, 2021).

20.4.2.1 Climate change commitments

Nations are aligning their energy strategies with international climate agreements. For instance, the Intergovernmental Panel on Climate Change estimates a 45% reduction in global CO_2 emissions by 2030 (compared to 2010 levels) and net-zero emissions by mid-century (Allen et al., 2022). This is in line with the goals of the Paris Agreement, which aims to keep global warming well below 2°C above preindustrial levels (United Nations Climate Change, 2022). At the moment, 197 countries have endorsed the Paris Agreement, and 195 have formally approved it. The remaining countries that have not yet formally joined are Iran, Libya, and Yemen (Denchak' and Hu;, 2025). All European Union countries are presently part of the Paris Agreement (European Council, 2025).

20.4.2.2 Sustainable energy development focus

Sustainability remains central to energy policies, with emphasis on universal energy access and equitable distribution of resources (Falcone, 2023; Routledge, 2024). Key frameworks guiding the focus of sustainable energy development include the SDGs (United Nations, 2022). The Paris Agreement (United Nations Climate Change, 2022), and several others. Thus, the ambition to develop the energy sector involves generating power from renewable and other clean energy sources. This transition from high-emitting energy forms aims to reduce environmental harm while ensuring a reliable energy supply to meet growing energy demands (Routledge, 2024).

20.4.2.3 Energy transition

The transition from fossil-based energy sources to clean energy, primarily renewables such as wind and solar, is commonly referred to as the energy transition (UNDP, 2025). This shift represents a significant transformation in how energy is produced, distributed, and consumed, with the primary goal of reducing carbon emissions and mitigating climate change. The energy transition plays a crucial role in addressing climate change, driving a global shift toward low-carbon energy sources (Adelekan et al., 2024). As a result, investments in petroleum projects have declined. However, this transition presents a challenge for nations and governments, requiring them to balance fossil fuel production with environmental sustainability (García-García et al., 2020). Achieving this balance necessitates well-structured policies that support a gradual yet decisive transition. To ensure a successful energy transition, a well-diversified power generation mix is recommended, enabling nations to meet their energy needs while advancing sustainability objectives (Nyasapoh et al., 2023; UNDP, 2025).

20.5 Regulatory frameworks: challenges and opportunities

The transition to sustainable energy systems presents a complex challenge that requires well-structured regulatory frameworks. Countries worldwide are working toward reducing GHG emissions, enhancing energy security, and fostering economic growth through energy policy reforms (Elkhatat and Al-Muhtaseb, 2024; Fu et al., 2021). Hence, effective regulatory mechanisms are essential in shaping the trajectory of energy transitions by ensuring fair competition, innovation, and market stability

(Radtke, 2025). However, multiple challenges hinder the efficient implementation of these policies, including bureaucratic inertia, outdated regulations, and conflicting interests from fossil fuel industries.

20.5.1 Challenges in regulatory frameworks

One of the major challenges in the energy transition agenda is regulatory fragmentation, where multiple agencies govern different aspects of energy policy, leading to inefficiencies and confusion (Eisner, 2000; Markard, 2018). Bureaucratic bottlenecks and resistance to change further slow the adoption of new technologies (Juszczyk et al., 2022). However, successful regulatory models, such as the United Kingdom's (UK's) Electricity Market Reform, demonstrate that well-structured policies can drive clean energy investments and innovation (Xenias et al., 2015). Thus, addressing these regulatory challenges requires a coordinated approach that streamlines governance, enhances transparency, and promotes collaboration among stakeholders (Mangal et al., 2025; Radtke, 2025).

Thus, energy policies worldwide are undergoing significant transformations as nations transition from fossil fuel-based systems to cleaner, renewable energy sources. This shift is driven by environmental imperatives, economic competitiveness, and energy security concerns (Adelekan et al., 2024; IRENA, 2022). Policymakers are tasked with creating frameworks that promote renewable energy deployment while ensuring equitable participation across various economic sectors (Adelekan et al., 2024). Key trends in current energy policies include geopolitical tensions affecting energy security, record growth in renewables despite persistent fossil fuel demand, and increasing market fragmentation due to trade policies restricting clean energy technologies (Nuhu et al., 2023; Shang et al., 2022).

In addition, geopolitical conflicts, such as the war in Ukraine, have significantly disrupted global energy supply chains, compelling countries to diversify their energy sources (Berahab, 2025; Metaxas, 2024). Simultaneously, international protectionist measures have introduced new barriers to the deployment of clean energy technologies, complicating global cooperation. The IEA projects that renewables are expected to grow by 2.7 times by 2030 globally, contributing more than one-third of global electricity generation. However, fossil fuels will still account for over 75% of primary energy consumption, highlighting the persistent challenge of reducing carbon emissions while maintaining energy security (IEA, 2024c).

Thus regulatory frameworks play a crucial role in overcoming barriers to renewable energy adoption (Obuseh et al., 2025; Oduro et al., 2024). Countries like Germany, China, and Denmark have successfully implemented policies that have transformed their energy landscapes. Germany's Renewable Energy Act (EEG 2000) introduced a feed-in tariff system that incentivised investments in solar and wind energy, leading to a renewable energy share exceeding 40% by 2020 (BWE, 2022). China's Five-Year Plans established mandatory renewable energy targets and grid access guarantees, positioning China as the world's largest renewable energy investor (Yale E360, 2024). Denmark's wind energy policy simplified grid connection procedures, fostering public support and enabling wind energy to account for nearly 50% of the country's electricity consumption (IRENA-GWEC, n.d; UNFCC, 2023).

Despite such success stories, many nations struggle with policy fragmentation and outdated infrastructure regulations. As such, the integration of diverse energy sources into existing regulatory frameworks remains a significant challenge, requiring strategic policy alignment across sectors.

20.5.1.1 Policy barriers and solutions

Table 20.2 outlines major regulatory challenges in energy transitions and presents policy solutions based on global best practices.

Technological advancements further complicate regulatory responses, as policymakers often struggle to keep pace with rapid, sustainable energy innovation (Zohuri and Mossavar-Rahmani, 2024). Economic constraints also limit the ability of governments to invest in necessary energy infrastructure upgrades (Calcaterra et al., 2024), while stakeholder conflicts can delay or derail energy projects (Radtke, 2025). Thus, effective stakeholder engagement is crucial to ensuring broad support for energy policy reforms.

20.5.2 Opportunities in regulatory frameworks

Despite the challenges related to regulatory frameworks, opportunities exist to drive sustainable energy transitions. Innovative policy instruments, such as feed-in tariffs, carbon pricing, and renewable portfolio standards, have proven effective in stimulating clean energy investment (Pitelis et al., 2020). International collaboration can also enhance knowledge sharing and facilitate financial and technical support for developing nations (Narteh, 2008; Pandey et al., 2022). Moreover, public-private partnerships (PPPs) can leverage additional resources for infrastructure development, while policies prioritising equity and inclusion ensure that marginalised communities benefit from energy transitions (Onifade et al., 2024).

Thus, the future of energy regulation depends on the ability of policymakers to integrate technological advancements, streamline governance, and foster international cooperation. By adopting flexible and forward-looking regulatory frameworks, governments can facilitate the transition to a sustainable and resilient global energy system.

For that matter, transforming the global energy system presents a chance for regulatory frameworks to evolve in ways that enable cleaner, more inclusive growth. While institutional bottlenecks remain, a shift toward adaptive and innovation-friendly regulations can unlock investments in renewables and accelerate energy transitions.

Fig. 20.3 highlights the steady increase in global installed renewable energy capacity from 2017 to 2030. Solar photovoltaics (PV) emerges as the fastest-growing energy source, followed by onshore wind. Hydropower maintains a strong base, while offshore wind and bioenergy gradually expand their roles. This trajectory reflects the potential impact of supportive policies such as renewable energy targets, technology-specific incentives, and grid integration mandates.

Table 20.2 Major regulatory challenges in energy transition and policy solutions.

Regulatory challenge	**Description**	**Suggested policy solution**	**Supporting references**
Policy Fragmentation or Policy Incoherence Across Sectors	Lack of alignment between various governmental departments and regulatory bodies results in conflicting mandates, regulatory overlaps, and implementation delays.	Establish centralised or harmonised governance structures that align national energy, climate, and development goals to avoid contradictions and streamline implementation.	Doumon et al. (2024), Kanda et al. (2022), Kivimaa (2022).
Infrastructural Limitations or Barriers	Ageing or inadequate grid systems cannot accommodate high shares of intermittent renewable energy, leading to curtailments and inefficiencies.	Modernise grid infrastructure with investments in digitalisation, smart metering, grid flexibility technologies, and energy storage systems.	Sareen (2021), Sovacool et al. (2022), World Economic Forum (2024).
Financial Constraints or Restricted Access to Capital	Renewable energy projects often require significant upfront investment, but financial institutions remain hesitant due to perceived risks and policy uncertainty.	Provide fiscal incentives such as tax breaks, green bonds, risk guarantees, and public-private investment platforms to de-risk renewable investments.	Calcaterra et al. (2024), Li et al. (2023).
Stakeholder Conflicts or Opposition from Incumbent Stakeholders	Resistance from fossil fuel industries, labour groups, and affected communities due to fear of job losses and economic decline in traditional sectors.	Implement 'just transition' frameworks that offer worker reskilling, community consultation, and social protection to promote an inclusive energy transition.	Hauenstein et al. (2023), Radtke and Löw Beer (2024), Schupfer (2024).

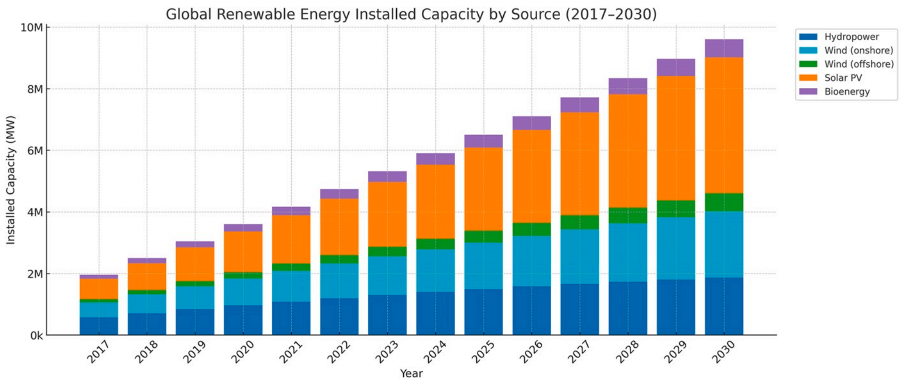

Figure 20.3 Global renewable energy.
Source: Adapted from J. Holub (2025). Renewable Energy Forecast for 2030. Rejobs Newsletter. https://rejobs.org/en/renewable-energy-blog/renewable-energy-forecast-for-2030IAEA, 2021IAEA. (2021). *Nuclear Energy for a Net Zero World*. https://www.iaea.org/site.

By embracing frameworks that encourage diverse technology uptake and ensure long-term policy certainty, governments can attract capital, support innovation, and enhance energy security. Aligning such policies with global trends seen in the figure creates room for cross-border learning and scalable solutions, particularly in emerging economies seeking to modernise their energy infrastructure (Pandey et al., 2022).

20.6 Technological innovations and policy integration

The integration of emerging technologies into energy policies is crucial for enhancing efficiency, grid stability, and sustainability. Innovations such as artificial intelligence (AI), smart grids, and hydrogen energy are reshaping the energy landscape and driving policy adaptation (Arévalo and Jurado, 2024; Cavus, 2025). Governments must therefore establish adaptive regulatory frameworks to maximise the benefits of the intelligent technologies and accelerate global energy sustainability goals.

20.6.1 Technological innovations

Technological advancements play a pivotal role in sustainable energy transitions by improving efficiency and reducing reliance on fossil fuels. Key innovations include:

- **Artificial intelligence in energy management:** AI is transforming energy markets by optimising electricity distribution, improving predictive maintenance, and balancing demand and supply (Onukwulu et al., 2023; Khan et al., 2023; Rojek et al., 2023). As a result, countries such as China, the United Kingdom, and South Korea have incorporated some key studies and have AI-based forecasting models into their national grids, reducing energy waste and improving reliability (Ali et al., 2024). Thus, AI-powered demand

response systems allow real-time adjustments to energy consumption, enhancing grid stability (Rojek et al., 2023).
- **Smart grid technologies:** Smart grids facilitate the seamless integration of distributed renewable energy sources, improving overall efficiency and resilience (Arévalo and Jurado, 2024). The European Union's Smart Grid Task Force has spearheaded regulatory frameworks that promote smart-meter deployment and real-time energy tracking (Leal-Arcas et al., 2017). In the United States, smart grid investments have reduced transmission losses by 10%, demonstrating the potential of policy-driven efficiency improvements and improved voltage stability and power quality (Allinson, 2024; Olatunde et al., 2024).
- **Hydrogen energy policies:** As countries explore decarbonization strategies, hydrogen energy has emerged as a key component of clean energy transitions (Cheekatamarla, 2024). For instance, Japan's Green Hydrogen Strategy (2020) provides subsidies for electrolysis projects, aiming to replace fossil fuels with hydrogen-powered systems (IEA, 2023; Nagashima, 2018). Similarly, the European Commission's Hydrogen Roadmap (2020) outlines incentives for hydrogen infrastructure development, positioning hydrogen as a central pillar of future energy strategies (European Commission, 2020).
- **Renewable energy integration and energy storage solutions:** Policies supporting grid modernisation and battery storage are critical to ensuring the large-scale deployment of renewable energy (Akinsooto et al., 2024). Technological improvements in photovoltaic cells, wind turbine design, and grid integration techniques have significantly reduced costs and improved performance (Adelekan et al., 2024). Since renewable energy sources are often intermittent, advancements in energy storage technologies are essential for grid stability (Asghar et al., 2023). Battery storage systems, pumped hydro storage, and other solutions enable better management of supply and demand fluctuations (IRENA, 2021).
- **CCS:** CCS is increasingly recognised as a critical technology for mitigating climate change. CCS involves capturing carbon dioxide (CO_2) emissions from industrial sources and securely storing them underground to prevent atmospheric release (Zhang and Huisingh, 2017). Innovations in CCS technology, such as hydrate formation methods, are improving efficiency and reducing costs (Bhati et al., 2024). However, challenges such as high costs and regulatory hurdles continue to limit large-scale adoption (Grant et al., 2022).
- **Hybrid energy systems:** Hybrid energy systems have evolved with renewables, with generators for mainly off-grid communities (Gabbar et al., 2020). However, two clean energy sources, such as nuclear and renewable hybrid systems, integrate both energy sources to enhance efficiency and reliability (Nyasapoh et al., 2025). The nuclear renewable hybrid energy systems provide a stable baseload power supply while leveraging renewable energy to meet fluctuating demand (IAEA, 2023).

20.6.2 Policy integration and future outlook

Emerging technologies are reshaping the energy landscape, calling for governments to establish adaptive policies that support innovation while ensuring regulatory clarity. Some of these effective policy measures include:

- **Incentives for technological deployment:** Feed-in tariffs, carbon pricing, and renewable portfolio standards have proven effective in encouraging investment in clean energy technologies (Bhamidipati et al., 2019). Hence, it is highly important to increase the energy sector incentives as an effective means of shaping a sustainable energy transition, especially for developing nations.

- **International collaboration:** Cross-border cooperation can facilitate knowledge-sharing and provide financial and technical support in the energy sector for developing nations (Radtke, 2025). For this reason, the energy transition agenda must not relax on effective cross-border collaborations to ensure the needed knowledge-sharing and provide financial and technical support for a sustainable energy future.
- **PPPs:** Engaging private sector stakeholders through PPPs can accelerate the deployment of sustainable energy infrastructure and enhance innovation (Onifade et al., 2024). More often, the readiness of the private sector to invest when collaborating with effective regulations and partnerships can lead to significant development in the energy sector. Once this is done, some funds from the public sector can be utilized effectively in other sectors for national development.
- **Equity and inclusion:** Ensuring that marginalised communities benefit from the transition to clean energy is crucial for policy success (Adelekan et al., 2024). As such, the growth and development required within international agreements and treaties can be achieved, ensuring sustainable energy for all, promoting education, healthcare, and the empowerment of marginalised groups.

Hence, the future of energy policy will depend on how effectively governments integrate emerging technologies into regulatory frameworks. By fostering innovation, improving grid infrastructure, and promoting international collaboration, policymakers can accelerate the global transition to a sustainable energy future for all. However, how the so-called policies are benchmarked to realise that they make the needed impact in ensuring energy transition remains a big question.

20.7 Measuring the impact of policies

Energy policies play a crucial role in shaping economic growth, energy security, environmental sustainability, and technological advancements (Bilgen and Sarıkaya, 2018; Dahlke et al., 2021). Thus, assessing the effectiveness of the policies is essential to ensure that they achieve the intended outcomes and inform future developments. Policy implementation and outcome evaluation provide a comprehensive assessment of policy impacts, guiding decision-making for ongoing improvements (Whitsel et al., 2024). Hence, effective evaluation of how policies are implemented, scaled, and funded can support prioritisation by policymakers, funders, advocacy organisations, and public agencies for the needed energy transition development.

20.7.1 Key metrics for evaluating energy policy impact

Assessing the effectiveness of energy policies requires the use of robust evaluation metrics. These indicators help measure success, identify gaps, and refine strategies for more effective implementation. Fig. 20.4 presents the key metrics for evaluating energy policy and is subsequently discussed.

- **Emission reduction metrics:** The decrease in GHG emissions resulting from policies, technologies, or operational changes can be assessed, tracked, and recorded. These emission reduction metrics enable governments, businesses, and organisations to quantify progress

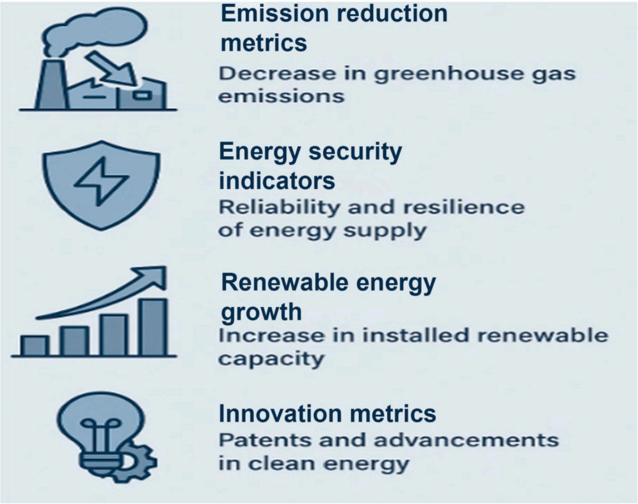

Figure 20.4 Key matrix for evaluating energy policy impact (Author draft).

toward sustainability goals and climate targets as enshrined or agreed upon internationally, such as the Kyoto Protocol (1997) and the Paris Agreement (2015) (UNFCCC, 2025).

- **Energy security indicators:** These indicators assess the reliability, affordability, sustainability, and resilience of an energy system. Such indicators help policymakers and industry stakeholders evaluate vulnerabilities and ensure stable energy supplies amid economic, geopolitical, and environmental challenges. For instance, the IEA was established in 1974 to respond to the global oil crisis and ensure coordinated energy security measures (IEA, 1974).
- **Renewable and clean energy growth:** The percentage increase in installed clean and renewable energy capacity serves as a measure of the effectiveness of clean energy policies in transitioning from fossil fuel dependency (Al-Shetwi et al., 2024; Yergin, 2020). As a result, efforts are being made to ensure clean energy sources such as renewables and nuclear enjoy a higher pace in the world energy transition (IAEA, 2021; Kabeyi and Olanrewaju, 2022; Nyasapoh et al., 2024).
- **Innovation metrics:** The number of patents filed in clean energy sectors, research and development (R&D) investments, and advancements in energy-efficient technologies indicate policy-driven innovation trends.

A summary of measuring energy sector policy success through key performance indicators is further presented in Table 20.3.

Energy policy adaptability and ongoing assessment with key regulations are essential to ensure long-term energy sustainability for shaping the desired energy transition globally. Therefore, policies must be dynamic, evolving in response to technological advancements, market shifts, and environmental concerns. By integrating continuous monitoring and evaluation frameworks, governments can refine energy policies to enhance the effectiveness of the policies and drive long-term progress toward sustainable energy systems.

Table 20.3 Measuring the impact of energy policies with key performance indicators (KPIs).

KPI	Measurement metric	Importance
Emission reduction	CO2 reduction per year	Indicates progress towards climate goals
Renewable energy growth	% increase in installed capacity	Measures the effectiveness of clean energy policies
Energy security	Reduction in energy imports, blackout frequency	Ensures national energy resilience
Innovation index	Number of patents, R&D investment	Tracks technological advancements in energy

20.8 Future directions for sustainable energy policies

Navigating the path of the challenges associated with energy policy adoption and regulations for shaping a sustainable transition requires careful strategies that should be considered. These strategies include:

- **Integrated policy frameworks:** Developing comprehensive energy policies that align economic, environmental, and social considerations enhances coherence across different sectors. Integrated frameworks foster collaboration among stakeholders and align incentives with sustainability goals (Mohammadi et al., 2023). Hence, energy and other sector policy frameworks must be well assessed and well aligned to achieve sustainable energy transition development.
- **Investment in research and development (R&D):** Increased funding for research and development (R&D) is critical in driving innovation in clean and smart energy technologies. As a result, policymakers must make a concerted effort and prioritise investments that facilitate technological advancements and encourage knowledge transfer between developed and developing nations (Adelekan et al., 2024). The process of transferring knowledge through R&D should motivate developing countries to accelerate learning by doing. This will help build the capacity for independent, effective collaboration and idea-sharing to support rapid progress in the energy transition agenda.
- **Strengthening international cooperation:** Global collaboration is essential for sharing best practices and resources necessary for successful energy transitions (Aisbett et al., 2023). Thus, the effectiveness of international partnerships can mobilise financing, facilitate technology transfers, and build capacity in developing countries' sustainable energy transition (Pandey et al., 2022).
- **Enhancing stakeholder engagement:** Effective engagement of stakeholders, including government entities, private sector players, civil society organisations, and local communities, is crucial for building consensus around energy policies. Thus, transparent communication strategies can foster trust and promote informed decision-making needed to drive a sustainable energy transition (Radtke, 2025). As a result, effective stakeholder engagement with collaborative efforts ensures that energy policies are inclusive and address the concerns of all affected parties to ensure the transition achieves its aim and targets.

- **Monitoring and evaluation:** Establishing robust monitoring and evaluation mechanisms allows policymakers to continuously assess the effectiveness of energy policies. This iterative approach enables necessary adjustments based on real national and world outcomes, ensuring that policies remain relevant and effective over time (Jefferson, 2015).

By adopting the strategies in line with national priority guidelines and leveraging opportunities for improvement, policymakers can create resilient energy systems that support economic growth, environmental sustainability, and technological advancement. Strengthening cooperation across sectors and regions will be essential in shaping a future of reliable and sustainable energy transitions.

20.9 Conclusion

The study set out to address a central challenge in recent times on how energy policies and regulatory pathways can be effectively aligned to accelerate a sustainable global energy transition. By dissecting global policy trends, institutional responses, and technological enablers, the research revealed that although many nations are making strides in renewable adoption and emissions reduction, progress remains uneven due to policy fragmentation, financial barriers, and infrastructure gaps.

The study's analysis shows that successful transitions hinge not only on the deployment of clean technologies like renewables, hydrogen, and smart grids but also on the adaptability of governance structures and regulatory clarity. International case studies demonstrated that where strong, coherent policy ecosystems exist, investment, innovation, and public support follow.

However, the study acknowledges its limitations, particularly the reliance on secondary data and the evolving nature of global energy frameworks, which could shift rapidly in response to geopolitical or economic changes. Future research could deepen this work by incorporating empirical field assessments or regional-level impact modelling to enhance policy specificity.

To truly realise a sustainable energy future, policies must move beyond ambition to accountability, embracing innovation, inclusivity, and long-term vision. The energy choices made today will determine not just the climate trajectory, but the economic and social resilience of generations to come. The moment for bold, coordinated policy action is now.

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