International Journal of Energy Systems and Power Engineering (IJESPE)
DOI: 10.5281/zenodo.14650732

Research Article

Dynamics and Drivers of Global Electricity Prices: Market Mechanisms, Policy Impacts, and Future Trends

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Cite as:
Omogoye, S. O., Adekunle, A. O., Adebayo, A. V., & Adebayo, H. K. (2025). Dynamics and Drivers of Global Electricity Prices: Market Mechanisms, Policy Impacts, and Future Trends. *International Journal of Energy Systems and Power Engineering, 5(1), 14-28.* *https://doi.org/10.5281/zenodo.14650732*

Abstract

This paper examines the dynamics and drivers of global electricity prices, focusing on the interplay between market mechanisms, policy impacts, and technological advancements. The study analyses various market structures and explores how renewable energy integration, decarbonisation policies, and technological innovations influence electricity pricing across different regions. The paper also investigates the role of carbon pricing and subsidies in shaping the future landscape of electricity markets, considering the implications for energy security, environmental sustainability, and economic stability. Through a comparative analysis of regional markets and projections of future price trends, this study provides insights into the potential trajectories of global electricity prices and the challenges and opportunities posed by the ongoing energy transition.

Keywords: Global Electricity Prices; Market Mechanisms; Renewable Energy; Decarbonisation Policies; Carbon Pricing; Energy Policy; Electricity Markets; Energy Transition; Electricity Subsidies

Introduction

Electricity is one of the few goods that do not have an inherent commercial value, and there are several ways to establish a price for this commodity (Shah & Chatterjee, 2020). Understanding the different electricity price components in regulated markets, including taxes, cross-subsidies, regulated tariffs, and incentive modulation, and how they can be established in multiple ways and with different objectives (Oprea & Bâra, 2021), is crucial. Under deregulated and competitive conditions, electricity prices are established using bidding mechanisms in power exchange and bilateral contracts known as over-the-counter contracts. Renewable energy has a direct impact on electricity prices. When this source generates an important part of the overall energy consumed, it leaves a smaller market for other conventional sources. Consequently, conventional sources become more expensive, increasing the market price (Liu, 2022). Prices can be increased due to the specific generation type, the design of national markets, international energy assistance, or other reasons. Moreover, we consider that the results showing the impact of renewable energy on the electricity price are relevant. That is, the price obtained in the market and the existing regulatory changes are simple effects to observe (Hu et al., 2021). Data were collected from the Elexon website, the REN 21 document, utilities, and academic research on the different ways to intervene in national electricity markets. Our study is focused on the European Union and some other countries that have their market cells opened to this market. In this paper, we hypothesise that the price of electrical energy will be reduced. However, this is remote or maintained if countries know how to correctly direct some measures that enable energy security, reduce unnecessary expenses, invest in industrial innovation, and achieve continuous economic development. Technological innovations, which are playing a significant role in shaping the future landscape of electricity markets, are the focus of our study, aiming to keep you informed about these latest developments.

Market Mechanisms

The restructured or liberalised electricity market has basic market mechanisms, such as demand response in the short-term market and price elasticity of the long-term price, which tightens the link between supply and demand (Lambin, 2020). However, fossil-fired, geographically centralised, and public monopoly systems of the past also faced risks of price spiking, leading to the adoption of new regulations (Chen et al., 2021). As liberalisation progresses, the risk of market failure increases, and this tightness may translate into systematic underinvestment, both in terms of capacity and market infrastructure, leading to severe consequences such as price spikes (Tsaousoglou et al., 2022). This shift towards a decentralised and green nature of liberalisation raises questions about what utilities are doing to delay it and the motivations behind their actions. Moreover, there are significant differences across channels. Utilities may attempt to impede the liberalisation process in electricity markets by designing new institutional arrangements to guide investment for upgrading generation capacity and ensuring long-term supply adequacy in the central regions (Sousa & Soares, 2020). In "old" markets, which have already or are nearly wholly restructured or liberalised, the process of liberalisation—coupled with the fact that coal, gas, and nuclear power have maintained their dominance in electricity generation—has influenced market dynamics (Stanelyte et al., 2022). These traditional energy sources have historically benefited from not having to normalise generation capacities or set generation prices, making them the most variable-cost-efficient generation technologies in the short term. As these markets evolve, their strategic importance, especially during specific situations, is underscored by the widespread retrofitting investments that provide both direct and indirect operating and long-term supply capacity adequacy.

Supply and Demand Dynamics

There are three primary drivers of the global market dynamics of the price of electricity. The first derives from supply and demand dynamics in separate geographical or internationally connected markets. Generally, local prices are greatly influenced by the specific conditions and constraints of the market under analysis and by the availability and quality of international electricity interconnections (i.e., transmission capacities) or backstop technologies in the short or long term (Poplavskaya et al., 2020). Geographical differences in fuel costs mainly determine prices, the cost of investing in new power plants, carbon prices, and actual policy implementation in specific markets and countries (Božić et al., 2020). The level of cross-border exchange itself is influenced mainly by the difference in short-term marginal costs between interconnected marketplaces, and this will set the level of electricity exchange between countries and the design of balancing markets and mechanisms. However, different retail electricity prices and regulatory constraints on plant operations might heavily influence actual short-term market disequilibria and an accurate representation of marginal cost differences, excluding investment needs, based mainly on fuel costs. In principle, the cost of electricity production for base-load operation (24 hours) must be identical for all units independently of the length of production time, as the unique price-setting unit determines it at a given time. Moreover, given structural costs, all resources should be compensated for contributing to the system across the covered years of their useful life (Spodniak et al., 2021).

Nevertheless, underinvestment decisions are reflected in market disequilibria and reflect mainly the difficulty in judging who should cover the structural cost of resources, such as capacity payments associated with various types of reserve, peaking, and system flexibility resources, rather than the short-term contribution to the market. Decreasing or periods of hostile prices are associated with over-capacity conditions in the system. They are generally not directly linked to market design features regarding how well reserves operate between interconnected system parts. This may also cause inefficient regulatory framework design for one or more interlinked systems (Nguyen & Paczos, 2020). Finally, at vast levels of penetration of vRES, energy markets (i.e., the electricity price) will show increasing price volatility, which may be too high for market participants used to a system with less volatile prices.

Wholesale Market Structures

To embrace the above question, a closer examination of the nature of their market structures for that part of the deregulated industry seems informative first. We observe various wholesale market structures across these deregulated regions (Dedoussi et al., 2020). Table 1 presents a set of distinguishing characteristics of each of these regions. The five regions in the United States are the most mature wholesale markets. These markets notably differ from the more recently implemented markets like Alberta and Ontario, Canada, Mexico, Italy, and New Zealand, which have contributed data for less than ten years (Arnett & Mitra, 2020). Critical characteristics of selected wholesale markets. Despite this diversity, there are essential common attributes. The wholesale market refers to markets within which generation-related transactions are negotiated (security-constrained unit commitment, scheduling of generation resources, and sales of energy, capacity, and the needed ancillary services) (Russo et al., 2020). Obligations about the transmission and distribution of electricity (for example, provision of transmitting lines, voltage transformation, and distribution of electricity) are the responsibility of a regulated entity. They are treated distinctly in all wholesale markets. It will be seen that a balance of various types of wholesale markets has emerged (Phua, et al., 2020).

Price Formation Mechanisms

There are complex mechanisms that determine electricity prices with multiple time scales. At the highest level of abstraction, electricity is different from an ordinary commodity market in two key senses. First, electricity is a flow, not a stock, and generation and consumption levels must be equal instantaneously. Every market must be transparent in real-time (Albertus et al., 2020). Second, electricity cannot be stored on an industrial scale except in tiny amounts relative to actual demand levels. Hence, supply and demand must always be balanced (Lu et al., 2020). Because of these physical constraints, there is zero elasticity in demand except at the concise end of the response time scale; price plays a crucial role in managing this demand-response flexibility (Lu et al., 2022). The mechanism of electricity price formation occurs through several different markets at several different time scales. At the most aggregated level of detail, the first effect in the determination of electric prices is the day-ahead processes used to schedule the operation of a diverse range of units (hydro, nuclear, coal, gas, oil, biomass), many of which become price-setting (Zhang et al., 2020). These are typically followed by markets where adjustments are made just before or during system operation (ancillary services such as voltage regulation, frequency regulation, black start, spinning reserve, and non-spinning reserve) under which electric power systems operate on various time scales—seconds, minutes, quarter-hours, hours, and longer to days. These markets are used to ensure the reliability of the operation and fair compensation to the providers who support the systems (Tushar et al., 2020). Different market power issues and government intervention strongly influence these mechanisms.

Table 1: Comparison of Electricity Market Structures in Selected Countries

Country	Continent	Market Structure	Key Characteristics	Impact on Prices
United States	North America	Deregulated	Competitive wholesale and retail markets	High price volatility, market-driven
Germany	Europe	Partially deregulated	The mix of the market and regulatory controls	Moderate volatility, policy-driven
China	Asia	Regulated	State-controlled pricing and generation	Stable prices, less market efficiency
France	Europe	Regulated with Market Elements	State-influenced pricing with some market features	Stable prices with occasional adjustments
Brazil	South America	Partially deregulated	Combination of regulated and market-based pricing, growing renewable sector	Moderate volatility, influenced by energy mix and policies
Australia	Oceania	Deregulated	Essentially competitive market with significant renewable integration	Price fluctuations are driven by renewable integration and market forces
South Africa	Africa	Regulated	State-owned utilities dominate the market and limit competition	Stable prices, but challenges with reliability and infrastructure
India	Asia	Partially deregulated	The mix of regulated tariffs and market-based mechanisms, high reliance on coal	Moderate to high volatility, driven by fuel costs and policy changes

Japan	Asia	Deregulated	Competitive market with high dependence on imported energy, significant regulation	Price stability with occasional fluctuations due to fuel imports
Egypt	Africa	Regulated	State-controlled, with heavy subsidies on electricity prices	Artificially low prices due to heavy subsidies, limited market efficiency

Policy Impacts

Policies tied to the planet's health, human well-being, national security, and industry competitiveness directly and indirectly impact global electricity prices. These policies are sometimes relatively transparent (e.g., carbon prices). In contrast, in others, the impacts are less visible or are manifested through social and environmental regulations that are not directly linked to the electricity system (e.g., transportation and land use policy, water quality regulation) (Guan et al., 2023). However, policy costs generally reflect the same underlying economic concepts as fuel costs and competition, with some differences, such as the likelihood of limited recovery of costs through market prices and market responses (Ike et al., 2020). Policy impacts stem from the role of electricity systems as a supersector with links to the economy and society through myriad interconnections. In the economy, electrification competes as an end-use service with labour in some automated tasks and with direct uses of power and heat, as well as tradable and non-tradable secondary energy (Ari et al., 2022). Demand response enables electron-based storage, promoting new flexibility interconnections and modular, distributed energy resources; real-time pricing can impact the physical waveforms of system operations by shifting demand and enabling more efficient actions from some supply options (Parry et al., 2021). In society, national and local communities depend on the reliability of electricity systems for economic welfare and health, which may involve political decisions about barriers to investments (through planning laws) and price floor protections to assure diversity (in multiple dimensions of resources) and immunity to long-term impacts of exogenous price shocks (Duan et al., 2021).

Regulatory Interventions

A government may also play a role in the market by connecting and disconnecting assets from the transmission grid, influencing connections to the grid, or influencing future investment by encouraging or preventing private sector development (Sgaravatti et al., 2021). Additionally, the need for tax revenue collection encourages governments to extend site-specific level costs into outliers and force price convergence, subject to increasing progress of the regulator where there is a facility-sharing capacity (Burgess et al., 2020). Regulated electricity tariffs ultimately announce the consumer price (Ari et al., 2022). The regulatory myths have several consequences for how system prices are calculated relative to the ability of demand to follow the electricity price by direct response, often requiring no price-driven modernisation at all of the traditional electricity demand side transactions (Fowlie et al., 2021). A public administration's announcement of the shift price is merely an adjacency to how demand reacts to imbalances in generation and capacity-enabling options. It need not be the same as what a system price to the market might look like, mainly if future electricity demand were supplied.

Renewable Energy Policies

Renewable energy technologies have led to the expansion of renewable energy deployment across the globe. Several policies have been enacted to promote this growth. For instance, feed-in tariff (FIT) policies and targets, as well as funding research and development (R&D) investments, have been crucial in reducing renewable energy costs and supporting renewable energy penetration (Neuman et al., 2021). FIT policies, in particular, have historically been the most successful policy instruments to promote renewable energy development. The most well-known example is the German Renewable Energy Sources Act (EEG), which has, in turn, become the basis for several similar laws worldwide (Li, 2021). As of 2020, electrical energy from renewable energy sources was supported in at least 144 countries with feed-in tariffs, a feed-in premium, investment rebates, or other regulatory policies (Carbassé Mumbrú, 2023). In the U.S., with its 53 renewable portfolio standards (RPS) laws and mandates, RPS has been the primary policy instrument to promote renewable energy deployment. This has been supplemented with tax credits, net metering, and various investment subsidies and programs (Resch et al., undefined). The 2021 to 2029 U.S. government tax credits and rebates value $10.5 billion and $16.5 billion for solar and wind power, respectively.

These and other instruments have allowed the U.S. to double renewable energy generation to a 20.4% share of total U.S. electrical energy generation from 2010 to 2020. That figure excludes hydro-generated electricity and includes wind, solar, biofuel, and highly contentious biomass power. As shown in Figure 3, the specific policy instruments in place in any nation and the regulatory environment can lead to significant variation in the renewable energy share of each national market. This variability in policy implementation happens even within nations due to the coexistence of different state-level incentives, standards, and support systems for renewable energy projects. In many African nations, where the goal is to increase access to electricity, governments rely on public funds to invest directly in these projects.

Carbon Pricing Mechanisms

Introducing carbon pricing mechanisms is becoming a popular policy choice, similar to those employed in the European Union, Australia, California, and China. The most popular forms of carbon pricing employ cap-and-trade mechanisms or direct taxes on carbon emissions. Both policies essentially function by imposing an additional levelling cost on power generators that use carbon-based power sources (Stavins, 2020). As a result, the introduction or strengthening of such carbon pricing regimes has been documented as having shifting price impacts, especially during peak hours as the demand and generation mix changes (Green, 2021). Furthermore, these mechanisms also help to moderate price spikes by, in effect, activating marginal plants that predominantly use less-pricey natural gas (Lilliestam et al., 2021). However, the observed impacts of carbon pricing institutions have prompted concerns that such carbon levies may eventually solely increase electricity and natural gas prices, erasing any potential benefits. Recent research finds that such impacts can be partially offset if carbon allowance revenues are employed to support renewable generation, such as through subsidies or funding the price of green power (Rosenbloom et al., 2020). In doing so, the subsidy and the tax are set depending on how much green generation benefits from carbon levies. However, that approach likely offers an inadequate incentive to stimulate additional green portfolios. Still, whether such offset policies can provide a positive boost remains an open empirical question. The complex network of green subsidies, fossil fuel taxes, and energy prices also entails the need to address their effects on the terms of trade of modern industrialised economies.

Table 2: Impact of Carbon Pricing on Electricity Prices in Selected Regions

Region	***Continent***	***Carbon Price (USD/ton)***	***Electricity Price Increase (%)***	***Primary Energy Source***
European Union	Europe	30	15	Mix (High renewables)
California	North America	20	10	Natural Gas, Renewables
China	Asia	10	5	Coal
Brazil	South America	5	3	Hydropower, Renewables
South Africa	Africa	8	7	Coal, Renewables
Australia	Oceania	15	8	Coal, Natural Gas, Renewables
India	Asia	7	6	Coal, Renewables
Japan	Asia	25	12	Nuclear, LNG, Renewables
Canada	North America	20	9	Hydropower, Natural Gas, Renewables
Saudi Arabia	Asia	0	2	Oil, Natural Gas

Subsidies and Tariffs

Subsidies encompass direct incentives to promote domestic electricity production (renewables and fossil fuels) and electricity access in unelectrified or underserved areas. Across all countries, the average electricity support is just as significant as the estimated adverse effects of electricity generation (Rahman et al., 2022). The composition of this average electricity subsidy for high-, middle-, and low-income countries is diverse; mainly, fuel subsidies are distinct for medium- and high-income countries (Borenstein & Bushnell, 2022). We propose a subsidy reform strategy that ensures few adverse welfare effects and increases overall global welfare, contingent on sufficiently large damages from electricity generation that justify the current level of global subsidies. We estimate the declining block electricity tariff that reflects the consumption decision for the residential tariff structure used by 1,942 utilities in 96 countries. We also examine the disutility generated by purchasing power from the grid and the utility of access and find important utility-enhancing differences between rich and poor households (Bamati & Raoofi, 2020).

Table 3: Comparative Electricity Prices in Different Regions (2023)

Region	Average Electricity Price (USD/kWh)	Dominant Energy Source	Market Structure	Key Influences
European Union	0.25	Renewables, Natural Gas	Competitive, regulated	High renewables, carbon pricing
North America	0.15	Natural Gas, Coal	Deregulated, regulated	Fossil fuel prices, policy
Asia-Pacific	0.20	Coal, Renewables	Mixed	Energy mix, economic growth
Middle East	0.10	Oil, Natural Gas	Regulated	Fossil fuel subsidies

Technological Innovations

Electricity power markets are inherently capital-intensive, long-term, and technology-driven businesses with large fixed infrastructure costs and almost no variable costs. Therefore, it is crucial to assess and predict the potential impact of technological innovations on the electricity markets (Salkuti, 2021). Science and technology-related forecasts suggest that several innovations can transform the energy landscape over the next 20 to 30 years. The lower cost of solar and electric vehicle battery technologies might enable lower-cost power storage, significantly impacting energy usage patterns (Balali & Stegen, 2021). Although a technology known as blockchain was first used in cryptocurrencies such as Bitcoin, it is now also being proposed as a solution for managing peer-to-peer transactions on electricity markets (Needell et al., 2023). Information and communication technologies such as sensors, cloud computing, and big data can potentially transform many energy markets and expand existing markets. The electrification of heat and transport, including adopting electric vehicles and heat pumps, can disrupt the electricity market (Kamath et al., 2020). The fundamental economic problem is that the low marginal cost of electricity implies that infrastructure built at high fixed costs does not recover its embedded capital, causing rate structures to produce below-average prices during periods of peak demand. New technologies and demand response solutions that lower peak demand can ameliorate this problem, reduce high price volatility, and improve the efficiency of power markets. In the energy world, particularly electricity, technological, research, and development advancements are the only disruptive changes parametrically impacting security, affordability, and environmental sustainability.

Smart Grids and Energy Storage

In addition to energy efficiency (the subject of a dedicated section above), carbon capture and storage, and demand response—already mentioned—that can significantly aid in the decarbonisation of electricity systems, "smart grids" and energy storage are likely more central to price trends now (Tan et al., 2021). Smart grids and energy storage have received much attention under global "smart cities" initiatives. This attention is well-earned as they can be deployed to address current problems, unlike many proposals for hydro and nuclear power, which, while worthwhile, take longer and require large capital outlays (Diahovchenko et al., 2020). Moreover, demand-side resources can affect the entire supply-demand balance by influencing both. In other words, the appropriateness of robust and efficient market structures, such as those sought in this chapter, can, to some extent, be sensitive to the scale of attempts to use smart grid capabilities to disrupt the price discovery role of today's markets, potentially displacing millions of hours of investment for billions of dollars of losses from inefficient price signalling (Meliani et al., 2021).

Battery breakthroughs alone may not (though they certainly could) reduce the length of time needed for a low-carbon transition to a decade, especially given the accelerating relative importance of coal in a system building out wind and PV, as well as steady contributions from nuclear and geothermal sources (Rezaeimozafar et al., 2022). The ability to progress towards large "baseload" geothermal generation will also influence the magnitude and composition of future storage investments. The processes currently underway, such as curtailed gas plants or CCGT-LNG plants provoking financial instability in electricity network investments, only partially parallel how the ongoing fracturing of natural gas markets has reduced the time over which large gas infrastructure has meaningful roles. The smart grid and demand response options can help to bolster flexible baseload generation, which both lowers the risk of such instability and better distinguishes the characteristics of generators before it becomes necessary. The contribution of today's dispatchable capacity is enhanced to the extent that investment exposes weaknesses in market structures, thereby setting other interests that will be impacted by deploying transportation fuels in electricity markets.

Distributed Generation Technologies

Distributed Generation (DG) or decentralised generation refers to the use of small-scale technology to generate electrical power close to the end-users of the power. It includes a range of technologies, both renewable and fossil-fuel-based, such as solar PV panels, biomass and biogas generators, small-scale hydroelectric generators, micro-wind turbines, and small natural-gas-fired gas turbines (Iweh et al., 2021). Most investments in DG occur in advanced economies where incentives bridge the gap between DG investment costs and lifetime revenue streams (Rani et al., 2024). Since DG is often invested in residential settings, it can have the unexpected distortionary impact of reducing traditional utilities' revenues, which induces those utilities to increase consumer electricity costs, indirectly financing their traditional business model (Karue & Murage, 2022). In recent years, DG has experienced significant growth driven by technological advancements and government enablement of prosumers through support mechanisms and grid access (Verma & Kashyap, 2021). The main drivers recognised in the literature are a supportive policy framework, energy-price reduction, enhanced security of supply, environmental benefits, and technological advancements, i.e., efficiency improvements in both electricity generation and the management of electricity demand, primarily stemming from the digitalisation of relevant systems such as smart meters. The most recognised challenges are related to the fact that DG is best achieved close to electricity end-users, i.e., distribution networks close to homes and industries, thus increasing the need for grid reinforcement and, depending on the DG technology, demand-side response management.

Declining Costs of Solar PV and Wind Energy (2010-2023)

The potential increase in renewable energy incorporation into the energy sector has been backed up by the substantial decline in solar photovoltaic (PV) and wind power generation costs since 2009. Due to the rapid advancements in technology and the upscaling of installations, solar energy costs have dropped significantly, making wind energy cost-competitive in many regions of the world (Ram et al., 2020). As a result, new renewable projects have become more cost-effective compared to existing plants, shifting the focus of the energy transition beyond just the installation of zero-marginal-cost renewable technologies to the design of energy policies that support clean technology, ensuring reliable and secure supplies alongside investments in supporting mechanisms (Joshi et al., 2021). From 2010 to 2023, the cumulative installed capacity in the solar energy sector increased by over 4000% globally, while the stock of wind power exceeded £75 billion in 2023 after increasing by more than 8000% during the same period (Li et al., 2022). In the UK, the new stock of solar PV plants surpassed all initially installed capacity by 2021, while the same year saw a remarkable increase in installed wind capacity over the cumulative installed base. Since 2012, most new capacity builds have been from larger (>5 MW) renewable sectors, accompanied by an accelerated phase-out of large conventional units. Figure 1 illustrates the declining costs of Solar PV and Wind Energy from 2010 to 2023. The chart shows a significant reduction in the cost per megawatt-hour (MWh) for solar photovoltaic and wind energy, reflecting the impact of technological advancements and increased installation capacity.

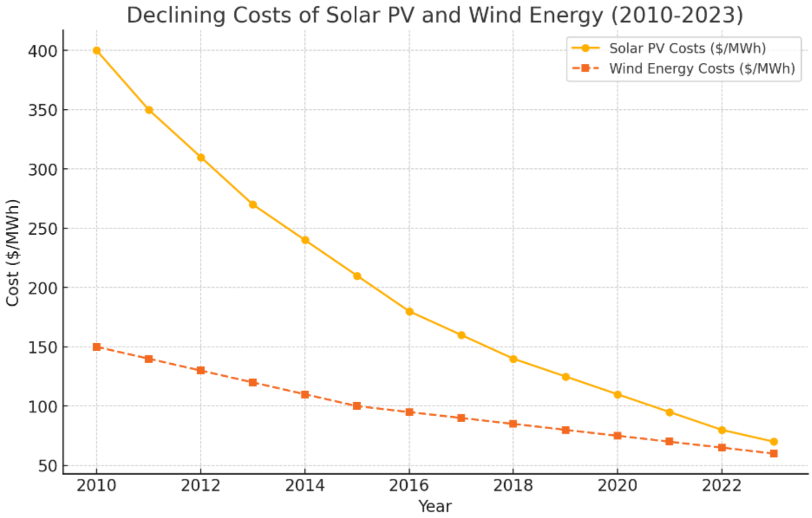

Figure 1: Declining Costs of Solar PV and Wind Energy (2010-2023)

Investment signals are provided by the carbon price, which drives demand for available low-carbon flexible units during negative shocks in renewable output, thereby altering local electricity prices. Additionally, the systematic capacity sector justifies dedicated offers for flexible technologies by stimulating an allowance-based capacity market to address the perceived reliability gap. Synergies between the power calls and those addressing newly revealed carbon avoidance challenges are pursued by adapting existing power system designs. The reliability demand is stimulated, emphasising capacity adequacy in a decarbonising world characterised by declining natural demand, which is necessary under different ambitious carbon reduction and capacity levels. Furthermore, efficient solutions that can contribute to policy trade-offs among reliability concerns and potential carbon footprints are essential for providing fair and valuable functionality in a supportive policy environment.

Fuel Prices

Global energy prices have increased considerably after a significant decline between the early 1980s and the late 1990s. The most recent oil price hikes have dramatically boosted energy costs. The European pricing organisation notes that the primary fuel used for oil indexation for gas prices is now traded near $100 per barrel. This represents more than a threefold increase compared to the minimum observed on the American market in 2000, and prices as low as $10 per barrel prevailed over the previous decade (Kober et al., 2020). The recent evolution of energy prices reinforces the economic motivation for resource and demand conservation once the new price equilibrium becomes evident (Van de Graaf & Sovacool, 2020). Economic reasons exist to believe that world energy prices might remain high in the long run. However, the near-term futures market signals the possibility of falling prices, as was observed by energy market analysts over the summer of 2008 (Semieniuk et al., 2021). In this paper, we will describe the link between energy prices and those of other commodities (e.g., agricultural products) to verify whether the world's energy problem has historical analogies in the economic crises due to the tightening of energy consumption after a preceding period of rapid growth, similar to the events at the end of the 19th century. Fuel prices, particularly for natural gas, coal, and oil, are primary determinants of electricity prices in many regions. Fluctuations in these prices can cause significant variability in electricity costs, especially in markets heavily reliant on fossil fuels.

Table 4: Correlation between Natural Gas Prices and Electricity Prices in the United States (2010-2023)

Year	Natural Gas Price (USD/MMBtu)	Average Electricity Price (USD/kWh)	Correlation Coefficient
2010	4.50	0.12	
2015	2.75	0.10	0.85
2020	3.00	0.11	
2023	5.00	0.14	

Comparative Analysis of Regional Electricity Prices

This study compares electricity prices across regions. Given substantial full-pack costs in nuclear and renewable energy, mainly hydro and offshore wind, we compare prices considering an extended range of drivers from 2008–2016. These drivers include cost and price components due to long-term capacity expansion needs and short-term demand for balancing capabilities. The analysis is based on explicit modelling of merit order dispatch gross hourly and carbon emissions prices in the English, Korean, Nordic, Quebec, and Spanish markets. The benchmark prices can thus be compared to those in other markets to gauge industrial sectors' international competitiveness and vulnerability for producers and end customers (Kolb et al., 2020). The suggested price components may provide a valuable tool for future price forecasting.

Electricity prices in many regions have become increasingly variable as the electricity sector transforms into energy and ancillary service markets. For example, the German day-ahead prices have exhibited extreme fluctuations, growing from €40 to more than €100 per megawatt-hour (MWh) between 2008 and 2016. Aside from the year-on-year benchmark, grid congestion often results in harmful price levels, such as those reached in California in 2002–2003 and Germany in 2017 (Frondel et al., 2022). Given substantial full-pack costs—due to decommissioning and waste handling—nuclear and renewable energy (mainly hydro- and offshore wind in the case of price variability at particular hours) can potentially become dominant factors affecting electricity prices. The study also suggests that autumn and winter periods will develop into less profitable intervals for photovoltaic energy, thereby increasing the significance of non-solar renewables in market prices (Spodniak & Bertsch, 2020).

Future Trends in Global Electricity Prices

Global electricity prices are increasing, and it is widely acknowledged that the growth of electricity prices will continue into the mid-to-long term. Recent studies provide a variety of forecasts for future electricity prices from several perspectives: some focus on pricing mechanisms and approaches, some on the mismatch between supply and demand, several consider relevant advantages of different energy sources, and some take a policy and institutional viewpoint (Perez & Garcia-Rendon, 2021). Fundamentally, a price and a policy are endogenous factors in the demand, supply, and market mechanisms equation. In other words, under a global carbon-constrained scenario, market mechanisms are expected to provide signals for technology innovation. The policy drives energy efficiency and greenhouse gas emissions reduction (Golubev et al., 2021). Taking a holistic and comprehensive view by considering supply and demand dynamics and drivers, including carbon constraints, we seek to provide both a meta-analysis and a forward-looking viewpoint. Electricity market power in the long term is expected to decrease as non-conventional energies such as solar, wind, and bio-energy increase their shares. Renewable technology's cost and suitability in several regions have made policymakers confident in achieving global carbon targets for 2050 (Zaghdoudi et al., 2024). In summary, future global electricity prices are subject to market and policy interventions. Moreover, achieving global carbon targets with renewable deployment to reduce market power, in practice, requires the market environment, power dispatch rules, institutional designs, and other particular cases to be designed and investigated. We expect the policy impact on wholesale electricity markets to be a hot research topic shortly.

Decarbonization Pathways

Economic decarbonisation pathways and deploying conventional and renewable energy resources are closely linked with expected market drivers and future electricity price trends discussed in this and earlier chapters. The choice of these pathways hinges on a large number of complex and often conflicting factors, including the availability of capital for investment, expectations about future policy and technology risks, existing commercial structures and attitudes, posturing by laggard industries, factions and countries, potential competitive strengths, specific public funding decisions, and general notions of fairness (Bogdanov et al., 2021). However, it is often hard to disentangle future trends in electricity markets and technologies from interested parties' biases and partial views. Currently, a tremendous amount of global effort, with some countries and organisations more active than others, is being channelled into modelling various pathways toward climate stabilisation and resource development and assessing their costs and benefits. Most use the tools of scenarios, pathways, and models and attempt to incorporate all the key elements of supply and demand, including the historical and expected future behaviour of economies, sectors, technologies, and energy resources, their level of service, efficiency and productivity, infrastructure requirements and characteristics, and rider and generator 'learning curves' (Webb et al., 2020). Some also consider externalities, environmental and other risks, and additional policy constraints, such as land use, water, and ecological impacts, the availability of critical elements, and concerns about energy security and political stability (Al-Shetwi, 2022).

Figure 2 shows the projected global electricity prices from 2024 to 2040 under different scenarios with varying renewable energy integration and decarbonisation policies. The graph compares three scenarios:

1. Low Renewable Integration, Minimal Decarbonisation: This scenario shows a gradual increase in electricity prices due to limited adoption of renewable energy and minimal decarbonisation efforts.
2. Moderate Renewable Integration, Moderate Decarbonization: In this scenario, renewable energy use and decarbonisation policies moderately increase, leading to slightly lower price increases.
3. High Renewable Integration, Aggressive Decarbonisation: This scenario projects a more stable or slightly declining trend in electricity prices, driven by significant integration of renewables and solid efforts to decarbonise solids.

The graph highlights how policy choices and technological advancements can significantly impact future electricity pricing.

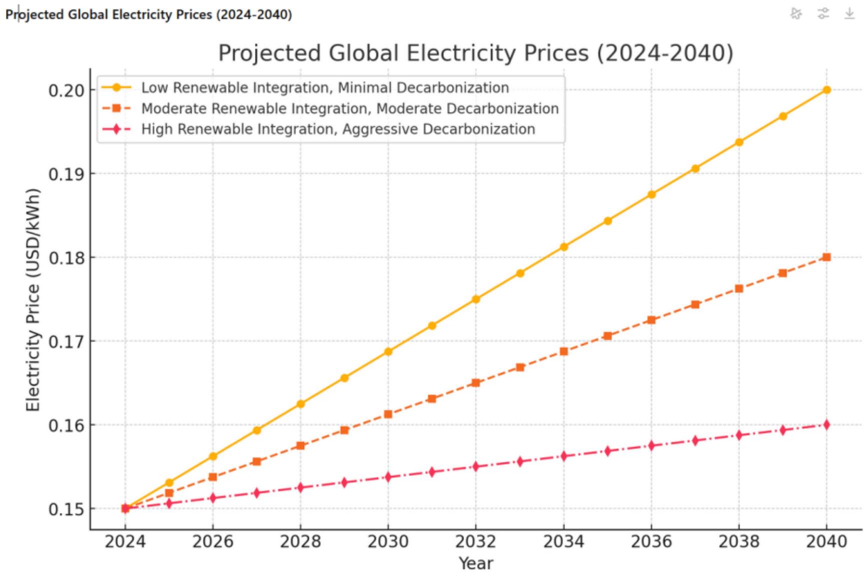

Figure 2: Projected global electricity prices (2024-2040) vary by renewable integration and decarbonisation policies.

Electricity Market Integration

Electricity markets have been structured in countries where supply and demand are large enough to warrant such an organisation. Internationally, the links are mainly through fixed contracts, with some limited spot trading on a regional basis. More significant, however, are the large international interconnectors used to transfer power, especially at times of generation scarcity (typically winter high demand) or, more recently, when there is a "policy ceiling" on domestic prices (Schmalensee, 2021). The theory underpinning market integration essentially rests on equalising the value of the traded commodities. If this is not possible—frequently seen in the case of natural gas due to differential prices for pipeline or liquefied natural gas (LNG) transport—then the second market integration condition depends on the willingness of countries and companies to deviate from equalised arithmetic prices and how robust enforcement mechanisms are in dealing with these deviations (Shittu & Santos, 2021).

Electricity takes a third path to commodity market integration. Various forms and quantities of electricity are traded through interconnectors at different prices to support the needs of consumers and generators of all participating countries. At a detailed level, there are still issues with legal harmonisation and the provision of harmonised conditions for different forms of market operation. For instance, institutional contracts between System Operators are generally bilateral. Some large multilateral points exist, but few allow trading across day-ahead and continuous intraday markets. According to economic dispatch and merit order principles, bilateral trading arrangements are also required to use existing transport capacity efficiently.

Impact of Energy Storage and Smart Grids

Energy storage (ES) is the latest emerging innovation that will impact energy markets significantly and might lead to a more efficient and resilient power market. Its potential to manage peak loads and integrate renewable sources is already recognised. The success and importance of energy storage are not under question. Smart grids (SGs), in combination with technology development, open the market for new business models and real-time supply and demand markets that enable ancillary service tariff efficiency. This might guarantee distribution network intrinsic resilience and operational performance and reduce network congestion and PER between generators, which could lower consumer costs. Future SGs will change the incumbents' operation techniques: the supply chain will be consumer-centric, and the new players will be aggregators, prosumers, demand response, and storage entities.

Conclusion

Dynamic drivers of electricity prices differ substantially across countries and over time. Questions such as the actual role of demand, subsidies, market concentration, regulatory interventions, or electricity exports in setting national electricity prices are typically answered using institutional analysis without empirical underpinning. In contrast to the existing literature, which is based on simulations of market outcomes or cross-section and time-series analyses of restricted or short data samples, this study estimates simultaneous equation models for 18 developed economies from 1990 to 2010. These models allow us to estimate the individual effects of supply, demand, environmental regulation, subsidies, and national market power on electricity prices across countries and differentiate between transitory and permanent nature effects.

Electricity prices in Finland, Norway, Austria, and the United States almost completely reflect the opportunity costs of production and power exchange within and across national borders. The Japanese and Greek electricity markets are also shown to reflect changes in the opportunity costs of electricity production, particularly the supply of fossil fuel generation, but with long and varied time lags. In Canada, Australia, and Denmark, increasing electricity demand, especially due to climate change, is the most important temporary driver of rising electricity costs. In contrast, the German electricity supply partially reveals market power in the long run while production costs are not mirrored within the day. In Spain, Belgium, and France, the evolution of their electricity prices is mainly driven by environmental policy interventions.

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