

An Empirical Analysis on Electricity Market Liberalization and Decarbonization Strategy in Japan

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Energy is fundamental to both economic activity and daily life. Yet the world continues to face the challenge of ensuring energy security, economic efficiency, and environmental sustainability simultaneously. Since the Industrial Revolution, fossil fuels have driven economic growth, but their geographical concentration and environmental impact have made energy systems increasingly fragile. Japan, which is heavily dependent on imported fossil fuels, has faced challenges in balancing a stable supply, affordability, and decarbonization. To address these structural issues, the country has pursued comprehensive reforms across institutional, technological, and administrative domains.

In the institution, the process of electricity market liberalization in Japan was initiated in 1995 and completed in 2016 with the introduction of full retail competition, resulting in the dismantling of traditional monopolies and the introduction of competition aimed at lowering costs, diversifying services, and promoting renewable energy. In the field of technology, the dissemination of smart grids and home energy management systems (HEMS) has been instrumental in enhancing the flexibility of energy systems and curbing CO₂ emissions through the optimization of real-time supply and demand balance. In the context of government digitalization, the establishment of the Digital Agency and the expansion of online administrative services have been cited as exemplars. These measures have been shown to enhance efficiency, albeit indirectly, through a reduction in paper use, office energy consumption, and mobility needs, which in turn has the potential to lead to a decrease in emissions.

However, despite these individual advancements, Japan's decarbonization policies often progress in isolation. Existing studies have largely examined each policy area separately, overlooking their potential synergies and interdependencies. This fragmentation undermines the effectiveness of national carbon neutrality strategies, particularly given the growing urgency of climate change. With CO₂ emissions from energy production and consumption accounting for roughly 73% of total greenhouse gases, the need for an integrated approach that aligns institutional reform, technological innovation, and administrative modernization has become critical.

This paper aims to empirically examine how electricity market reform affect the market structure and technology, and digital government collectively contribute to Japan's transition toward a decarbonized society. By analyzing their interactive effects, it seeks to reveal the mechanisms through which institutional and digital transformation foster technological adoption and environmental performance. The research addresses the central question of how policy coordination across markets, technology, and governance can enhance the effectiveness of

Japan's decarbonization efforts. So, this study contributes to the broader discourse on sustainable energy transition by emphasizing integration rather than fragmentation in policy design. It highlights the necessity of cross-sectoral strategies that simultaneously promote competition, innovation, and administrative efficiency. Ultimately, the findings are expected to provide policy implications for achieving carbon neutrality through coherent and mutually reinforcing institutional, technological, and digital reforms.

For electricity market reform, we examined how Japan's full electricity market liberalization affected the price elasticity of household electricity demand across regions and how the diffusion of photovoltaic (PV) facilities influenced electricity consumption. We used panel data from 2010 to 2021 of existing power companies except for Okinawa and examined the price elasticity using the regression analysis based on a logarithmic model.

Nationwide results show that before full liberalization, the estimated price elasticity was 0.53, which rose to 0.84 after liberalization. This indicates that household electricity demand became more responsive to price changes once competition was introduced, suggesting that consumers' sensitivity to electricity prices increased under a more competitive market environment. Additionally, the installation rate of residential PV facilities exhibited a statistically significant negative effect on electricity demand, implying that the spread of solar power generation reduced dependence on electricity purchased from utilities by increasing household self-generation capacity. At the regional level, notable differences were observed. Before full liberalization, the Shikoku region showed the lowest price elasticity for 0.145, while Tokyo recorded the highest for 0.958. After liberalization, elasticity rose in all regions, ranging from 0.409 in Shikoku to 1.259 in Tokyo. These findings reveal that urban areas such as Tokyo, Kansai, and Chubu experienced a greater increase in elasticity, exceeding 1, indicating a shift toward elastic demand. In contrast, rural regions like Hokkaido, Hokuriku, Chugoku, and Shikoku remained relatively inelastic.

These results suggest that the disparities in elasticity between urban and rural areas are strongly linked to differences in market competition and new entrant penetration rates. Urban regions, where new electricity providers entered the market more actively, likely experienced intensified competition, enabling consumers to choose among diverse pricing plans and thereby heightening their price responsiveness. Conversely, rural regions, with limited new entrants and less diversified options, exhibited weaker responsiveness. Moreover, the study identified a significant negative relationship between PV installation rates and electricity demand in major urban regions such as Tokyo, Kansai, and Chubu, where solar power adoption has been more widespread. This demonstrates that the expansion of distributed renewable energy systems in urban areas effectively reduced grid electricity consumption. Overall, the findings highlight two major implications. First, full retail liberalization enhanced the responsiveness of household electricity demand, especially in competitive urban markets. Second, the diffusion of PV systems contributed to reducing electricity demand through self-generation. These results emphasize the importance of considering regional heterogeneity in evaluating the effects of market reforms and renewable energy policies, as well as the potential synergies between market liberalization and the expansion of renewable technologies in shaping Japan's energy transition.

For the effect for technology, we employ a fixed effect model based on the IPAT framework to examine the factors influencing CO₂ emissions in Japan from 2007 to 2020, with a focus on smart grid technologies and other technological variables using OLS estimation. The analysis shows that the diffusion of smart meters significantly reduces CO₂ emissions by visualizing electricity consumption and encouraging energy-saving behaviors among households. Similarly, the adoption of residential PV systems lowers CO₂ emissions by decreasing reliance on utility-supplied electricity. Energy efficiency exhibits an inverted U-shaped relationship with emissions: initial improvements increase CO₂ emissions, but surpassing a threshold leads to substantial reductions. In contrast, the expansion of electric vehicles (EV) appears to create a rebound effect, increasing emissions. Among the four technological factors analyzed smart meters, PV installations, EV, and energy-efficient appliances, PV systems exhibit the largest impact, reducing CO₂ emissions by approximately 8%. In comparison, smart meters contribute only a modest reduction of 0.21% despite widespread adoption. These findings highlight the differential effectiveness of technologies in mitigating carbon emissions and underscore the importance of policy measures that support high impact interventions, particularly residential PV adoption.

We propose several strategies to enhance the effectiveness of smart meters and accelerate the adoption of residential PV systems. First, the CO₂ reduction potential of smart meters can be improved by integrating real-time data analytics with AI technologies. By analyzing consumption patterns, these systems can provide consumers and utility companies with optimized energy management strategies, encouraging more efficient behaviors and increasing emissions reductions. Second, the widespread deployment of PV systems should be actively promoted. This can be facilitated through a combination of consumer incentives and market-based measures. Additional tax incentives for companies in the PV sector could stimulate competition among solar panel manufacturers, thereby reducing system costs. Simultaneously, government subsidies, potentially delivered via time-limited vouchers, could further lower installation barriers and encourage prompt adoption. Collectively, these measures aim to make PV systems more financially accessible to both households and businesses, supporting a faster transition toward a low-carbon energy infrastructure.

For the effect for government digitalization, we examine the effects of government digitalization on CO₂ emissions in Japan using panel data from 47 prefectures between 2013 and 2023. A fixed effect model was constructed to quantify direct impacts, while a structural equation model (SEM) was employed to capture both direct and indirect mechanisms through which digital government initiatives influence emissions. The analysis yields several key findings. First, the fixed effect model indicates that a 1% increase in the issuance rate of my number cards corresponds to an approximate 0.005% reduction in CO₂ emissions, while a 1% increase in e-government utilization reduces emissions by roughly 0.001%, resulting in a combined reduction of 0.006%. Second, SEM results reveal larger effects by accounting for indirect pathways: the widespread adoption of my number cards reduces emissions by 0.008% directly, and indirectly by 0.006% through lower electricity consumption and 0.007% via decreased private vehicle mileage. Similarly, increased use of e-government services reduces emissions by 0.024% through electricity savings and 0.01% via reduced vehicle use, whereas regional DX initiatives contribute

to modest reductions of 0.002% and 0.001%, respectively. Notably, the expansion of shared online systems can paradoxically increase CO₂ emissions by 0.011% due to higher vehicle travel. Overall, the total CO₂ reduction attributable to digital government initiatives reaches 0.057%, highlighting the importance of considering both direct and indirect effects, as fixed effect model alone likely underestimate the true impact.

The study also identifies that CO₂ reduction effects are weaker in rural areas compared with nationwide averages. Based on these findings, several policy recommendations are proposed. Encouraging broader adoption of my number cards, such as for tax filing or document access, can reduce the need for in-person government visits and lower emissions. At the same time, the increased demand for online services should be coupled with strategies to manage transportation impacts, including promoting public transit and EV. Enhancing ICT infrastructure in rural areas, alongside improved public transportation options, such as car-sharing programs and community buses, can further strengthen the effectiveness of digital government in reducing emissions. Collectively, these results demonstrate that government digitalization contributes to CO₂ mitigation through multiple channels, and integrated policy measures are essential to maximize environmental benefits.

These results of studies highlight the necessity of a comprehensive, multifaceted approach to decarbonization in Japan, combining electricity market institution, technology and regional government policy measures. First, promoting green technologies, particularly the adoption of PV systems is essential. PV installations reduce household electricity demand and significantly lower CO₂ emissions. To overcome the high initial costs of installation, robust policy incentives, including subsidies, tax credits, and voucher programs, are critical to accelerate adoption among both households and businesses. Second, electricity market mechanisms are important to encourage behavioral change. For urban consumers, who tend to be more price-sensitive, can be motivated through dynamic pricing schemes that raise electricity rates during peak demand and reduce them during off-peak periods, achieving both energy conservation and peak-load management. The use of smart meters and HEMS enables consumers to monitor and visualize their energy use and mobility patterns, reinforcing voluntary energy-saving behavior. Finally, addressing regional disparities is crucial, as technological and market benefits are often concentrated in urban areas. Policy interventions should promote technology adoption in rural regions, facilitate entry of new energy providers, and strengthen ICT infrastructure and public transportation networks to reduce reliance on private vehicles and enhance the effectiveness of digital government services. Integrating these strategies ensures that decarbonization efforts are equitable, efficient, and effective across Japan's diverse regions.