Renewable Energy Adoption Across Business Cycles: The Impact of Economic Fluctuations and Policy Stringency

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Abstract

This paper analyzes the short- to medium-term dynamics of renewable energy adoption across 178 economies from 1985 to 2022, using the local projection method to assess the impact of economic fluctuations. The results highlight the countercyclical nature of renewable adoption, with recessions driving a shift towards renewables, while economic expansions initially slow this transition. Emerging economies with significant foreign investment exhibited the strongest shift towards renewables during recessions, while advanced economies showed more variable responses. Larger, diversified economies adopted renewables more readily than smaller, import-dependent ones, and energy-exporting countries increased renewable use during downturns but reversed the trend during booms. Policy stringency played a key role, as stricter regulations promoted lasting renewable adoption following recessions, though during expansions, only conventional policies—not market-based regulations—sustained the shift. These findings offer critical insights into how economic cycles and policy frameworks influence global energy transitions.

Keywords: renewables; local projection method; impulse response functions; recessions; expansions; economic groups; EPS.
JEL Codes: Q42, Q54, E32, O13, Q48, C32.

1. Introduction

The global push for sustainable energy transitions has gained urgency as countries aim to meet their climate commitments under the 2015 Paris Agreement. While global renewable energy capacity grew by 9.1% in 2021 (IEA), fossil fuels still account for 79% of global energy consumption. This highlights the critical role of renewable energy in decoupling economic growth from environmental degradation. Business cycles—periods of economic expansion and recession—significantly shape energy consumption patterns, with economic downturns often providing opportunities to shift towards cost-efficient renewable energy sources. Conversely, during expansions, economies may lean on fossil fuels to meet surging energy demands, potentially delaying the transition to renewables.

This paper investigates how different phases of the business cycle influence renewable energy adoption across economies. It explores whether recessions provide opportunities for accelerated renewable adoption and examines variations across economic structures and policy environments.

Theoretically, the countercyclical nature of renewable energy adoption aligns with the concept of creative destruction, where downturns spur innovation and technological shifts (Schumpeter, 1942; Deb et al., 2023). Recessions may encourage a transition to renewables due to their long-term cost-effectiveness, while expansions initially favor fossil fuels for their flexibility in meeting short-term demand (Rizwana et al., 2022).

Using data from 178 economies between 1985 and 2022, this paper employs local projection (LP) impulse response functions (IRFs) (Jordà, 2005) to estimate the short- to medium-term effects of economic fluctuations on renewable energy. It also applies smooth transition autoregressive (STAR) models to capture non-linearities across business cycles, focusing on economic types, policy environments, and energy mix variations.

The results confirm a countercyclical trend in renewable adoption, with a 1.4 percentage point increase in renewable energy following recessions and a temporary 3 percentage point decline during early expansions. Advanced economies show more variability in adoption patterns, while emerging markets, particularly those with higher FDI, demonstrate stronger renewable shifts during recessions. Energy-exporting nations shift towards renewables after recessions, reversing the trend during expansions. Environmental policy stringency (EPS) is crucial: non-market-based policies boost renewable adoption in both recessions and expansions, while market-based policies are more effective during downturns (Bachmeier et al., 2023).

These findings suggest that policymakers should strengthen non-market-based environmental regulations to support renewable adoption across all business cycle phases. Additionally, policies that attract foreign investment and reduce trade dependence can further bolster renewable transitions, particularly in emerging economies. Understanding the role of economic cycles in energy transitions offers essential insights for balancing economic growth with sustainability.

The paper proceeds as follows: Section 2 reviews the literature. Sections 3 and 4 discuss methodology and data, respectively. Section 5 discusses the empirical results, and Section 6 concludes with policy implications.

2. Literature review

The effects of recessions on energy consumption and mix are well studied, but less attention has been given to how energy transitions evolve throughout the entire business cycle, including economic expansions. This paper aims to address that gap by extending the work of Deb et al. (2023), who examined energy use during recessions, to also consider periods of economic growth. Additionally, it accounts for economy-specific characteristics deemed crucial by past research.

Deb et al. (2023) used local projection methods (Jordà, 2005) to estimate the effects of recessions on energy use and mix, applying the smooth transition autoregressive (STAR) model (Granger and Terävistra, 1993) to analyze the impact of environmental policy regimes on the share of renewables during downturns. Their analysis of 176 countries from 1965 to 2021 revealed that recessions lead to a permanent decrease in overall energy use and intensity, consistent with earlier research (Jalles, 2019; Li et al., 2020; Declercq et al., 2011). Energy use declined across sectors, and intensity dropped significantly over time, even after output recovery. During recessions, the share of renewables increased by 2 percentage points, as renewables, with low marginal costs, were more resilient.

These findings align with the notion of "creative destruction" during downturns, where obsolete infrastructure is replaced with more efficient alternatives (Schumpeter, 1942). As demand recovers, investment tends to favor renewable technologies. However, York (2012) found a proportionally larger growth in CO_2 emissions during expansions than the drop seen in contractions, particularly after the 2009 financial crisis. Peters et al. (2011) observed similar patterns of rising emissions during expansions, attributing this asymmetry to energy-intensive durable goods produced during growth periods.

Emerging market and developing economies (EMDEs) showed more limited renewable adoption during recessions compared to advanced economies. This disparity aligns with the findings of Peters et al. (2011), who noted limited impacts of the Global Financial Crisis on emissions growth in EMDEs, where fossil fuels remain essential for output acting as their primary source for growth (Adams et al., 2016). Jalles (2019) and Murshed (2023) emphasized the challenges EMDEs face in accessing capital for renewable investments during recessions.

Rizwana et al. (2022) examined recessions and booms in OECD countries, finding that recessions reduced renewable energy consumption more than non-renewables. Economic growth boosted demand for both, with foreign direct investment (FDI) improving energy efficiency and incentivizing renewables. This was confirmed by Li et al. (2022), noting that high FDI leads to a reduced transfer of pollution-intensive industries in developing economies. Conversely, Caetano et al. (2023) found that FDI in developing economies often increased non-renewable energy use, while Knutsson and Flores (2022) noted that FDI's shift toward renewables depends on climate policies.

Trade openness plays a significant role in shaping energy transitions. Alam and Murad (2020) and Thi et al. (2023) found that trade openness promotes renewable energy in the long run, while Muntasir (2024) noted its hindering effect for high-growth economies. Zhang et al. (2021) highlighted that exports boost adoption while imports hinder it. Meanwhile, energy-exporting countries face unique challenges, as the shift away from fossil fuels risks stranding assets (Fattouh et al., 2019; Shehabi, 2024).

Institutional quality and environmental policies are critical in shaping renewable transitions. Rizwana et al. (2022), Ahmed (2020) and Khalid (2020) demonstrated that stringent environmental policies, measured by the OECD's Environmental Policy Stringency (EPS) index (Koźluk et al., 2014), lead to greater renewable adoption, particularly in advanced economies.

This paper expands on previous studies by including a wide range of countries and applying local projections to estimate the short- to medium-term effects of economic fluctuations on energy transitions. While local projections are well-suited for short-term dynamics, this study focuses primarily on these timeframes to provide insights into the role of economic cycles in shaping energy transitions.

3. Methodology and Data

3.1 Econometric Approach

In this paper, we use the local projections method by Jordà (2005) to estimate the dynamic effects of business cycles on the energy mix. This method has gained traction in recent studies (Jalles, 2019; Pryagyan, 2022) as a flexible alternative to traditional vector autoregression (VAR) models, particularly for analyzing nonlinear responses. Local projections allow for direct estimation of impulse response functions (IRFs) without the restrictive assumptions of VAR models. This flexibility is crucial for capturing varying relationships between business cycles and the energy mix, accounting for differences in environmental policies and country-specific factors. Additionally, local projections handle lagged dependent variables more effectively, reducing the risk of bias and misspecification, making them ideal for short- and medium-term impact analysis. Our first regression specification takes the following form:

$$Y_{i,t+k} - Y_{i,t-1} = \alpha_i + \beta_k BC_{i,t} + \theta X_{i,t} + \varepsilon_{i,t} \quad (1)$$

where $Y_{i,t+k}$ is the natural logarithm of the energy consumption variable, in country i at date $t+k$, or in the case of energy mix regressions, the share of a specific energy source in total electricity. α_i are included to control for unobserved heterogeneity across countries, accounting for persistent differences in energy consumption and mix. $BC_{i,t}$ is our business cycle dummy variable, taking value of 1 during an economic recession (when real GDP growth is negative) and 0 otherwise. We will focus only on the first year of the crisis to capture the immediate and most severe recessionary effects[1]. $X_{i,t}$ is a vector of controls that includes two lags of the dependent variable (energy consumption or mix), the business cycle variable, and real GDP

[1] A common reason for choosing this approach is to minimise reverse causality problems. However, we chose it to isolate the immediate shock effect and minimise the chance that later periods of the recession could be influenced by other factors such as policy responses or recovery measures.

growth. Using lagged controls is essential to account for the persistence of energy demand and supply shocks over time.

Our IRFs track how recessions affect the energy mix up to five years after the shock (k=0,…,5), capturing both short- and medium-term dynamics. For each time horizon, we estimate the model using Ordinary Least Squares (OLS) with robust standard errors clustered at the country level. The coefficient of interest, β_k, represents the percentage point change in the energy variable following an economic shock, relative to a baseline scenario of no shock. We experimented with varying the number of lags in the model, finding the integrity of our projections was maintained across different lag specifications, underscoring the robustness of the local projections method in capturing the dynamic evolution of energy consumption following economic shocks.

We chose not to include time-fixed effects, following Deb et al. (2023), as our fixed-effect OLS regressions showed that including them significantly reduced our shock coefficient (see Appendix Table A1). This is likely because many major economic slowdowns in our sample are global, which time-fixed effects may not fully capture.

To further explore the relationship between business cycles and renewable energy adoption, we use the Smooth Transition Autoregressive (STAR) model, developed by Granger and Teräsvirta (1993). The STAR model allows us to capture nonlinear effects by letting the energy mix's response vary based on the state of the economy, providing flexibility in modelling transitions between recessions and expansions. The STAR model is specified as follows:

$$Y_{i,t+k} - Y_{i,t-1} = \alpha_i + \beta_k^L F(z_{i,t}) BC_{i,t} + \beta_k^H \left(1 - F(z_{i,t})\right) BC_{i,t} + \theta X_{i,t} + \varepsilon_{i,t} \qquad (2)$$

with,

$$F(z_{i,t}) = \frac{\exp\left(-\gamma z_{i,t}\right)}{1 + \exp\left(-\gamma z_{i,t}\right)}, \qquad \gamma > 0$$

$$\mathrm{var}(z_{i,t}) = 1, \ E(z_{i,t}) = 0.$$

In this function, $z_{i,t}$ serves as the business cycle index, typically interpreted as the real GDP growth rate, which indicates the current economic state. The transition function $F(z_{i,t})$ generates values between 0 and 1, allowing us to measure the likelihood of the economy being in a deep recession ($F(z_{i,t}) \approx 1$) or in a strong expansion ($1 - F(z_{i,t}) \approx 1$). The parameter γ controls the speed of transition between regimes, with higher values of γ indicating a more rapid shift between recessionary and expansionary periods. By following the approach of Auerbach and Gorodnichenko (2012) and Jalles (2019).[2] This model specification also includes two lags of the business cycle variable to account for potential inertia in the system, where past

[2] We set γ=1.5, which is consistent with the empirical observation that recessions in the United States occur approximately 21% of the time, according to NBER business cycle data.

economic conditions continue to influence the current energy mix. These lags are incorporated alongside the control variables from the baseline specification.

The STAR model's strength lies in its ability to capture smooth transitions between different economic states, rather than rigidly defining "recession" or "expansion" regimes. This approach makes the impulse responses more stable and precise compared to models that estimate effects separately for each regime. By allowing business cycle effects to vary continuously, we can observe how the relationship between energy transitions and business cycles evolves as economies shift between contraction and expansion. This is particularly relevant for our study, as it sheds light on renewable energy adoption during different phases of the business cycle. For instance, renewables may increase during recessions due to lower marginal costs, but this effect might weaken or reverse during expansions when fossil fuels become more competitive. The STAR model’s flexibility helps us better understand these nonlinear dynamics. In summary, the STAR model allows for a more nuanced exploration of the dynamic relationship between the business cycle and energy transitions, offering clearer insights into how these shifts occur in response to economic fluctuations.

3.2 Data

This paper will conduct local projection estimations in two main stages, beginning with energy consumption and production variables. For the first stage, we will examine the evolution of overall energy consumption using a large, unbalanced panel data set sourced from the Our World in Data energy database, a collaborative effort by researchers at the University of Oxford and the Global Change Data Lab (GCDL), with original data from the BP Statistical Review of World Energy. This data, covering 180 countries from 1965 to 2022, includes key variables such as oil, coal, and electricity consumption. These variables, transformed into their natural logarithmic form, will serve as the dependent variables in our baseline local projection regressions, allowing us to analyze the level changes in energy consumption following a recessionary shock.

In the second part of the first stage, we will use energy mix data to analyze the contribution of specific energy sources (fossil fuels like oil, gas, and coal, and renewables such as solar, wind, and hydro) to overall electricity production. The sample for this analysis includes 184 countries over a narrower period, from 1985 to 2022. Our primary dependent variable will be the evolution of the renewable share within the energy mix.

The second stage focuses on economic variables, which will primarily act as independent factors influencing the dependent energy consumption and mix variables. We will use annual real GDP growth data from the IMF’s latest World Economic Outlook database, covering 190 countries between 1980 and 2023. From this data, we define a recessionary shock as the first period of negative real GDP growth and use real GDP growth itself as a control in our regressions. While much research has explored different types of economic crises and their effects on energy consumption (e.g., Jalles, 2019; Pryagyan, 2022; Deb et al., 2023), this paper will focus solely on general growth events, by excluding extreme outliers—such as growth rates below -19.3% or above 24.5%.

The third stage of the analysis introduces variables for classifying economies. A trade openness index, sourced from the latest IMF World Economic Outlook, will be used to assess how dependence on international trade influences renewable energy adoption, with data available from 1965 onward. Another key parameter is foreign direct investment (FDI), representing net inflows from foreign investors as a percentage of GDP. FDI, crucial for financing renewable infrastructure projects—particularly in emerging economies—will be analyzed, though we acknowledge its sporadic availability, with data beginning only in 1990. Both trade openness and FDI will be used to classify economies into upper (above the global mean) and lower (below the global mean) groups. Additional classifications, such as development levels and energy-exporting status, will be based on World Bank classifications.

To evaluate the impact of policy, we will use the environmental policy stringency (EPS) index, sourced from the OECD's EPS dataset, which covers 33 OECD countries from 1990 to 2020. This dataset includes a range of policy instruments such as emissions taxes, feed-in tariffs, emissions limits, and R&D subsidies, with stringency measured on a scale of 0 to 6.

To ensure the stationarity of our data, we conducted Augmented Dickey-Fuller (ADF) tests. Given our large dataset, spanning decades and 180 countries, we used the inverse normal statistic (Z) as recommended by Choi (2001) (see Appendix Table A2). A comprehensive list of variables, along with their descriptive statistics, is provided in the Appendix Table A3.

4. Empirical Results

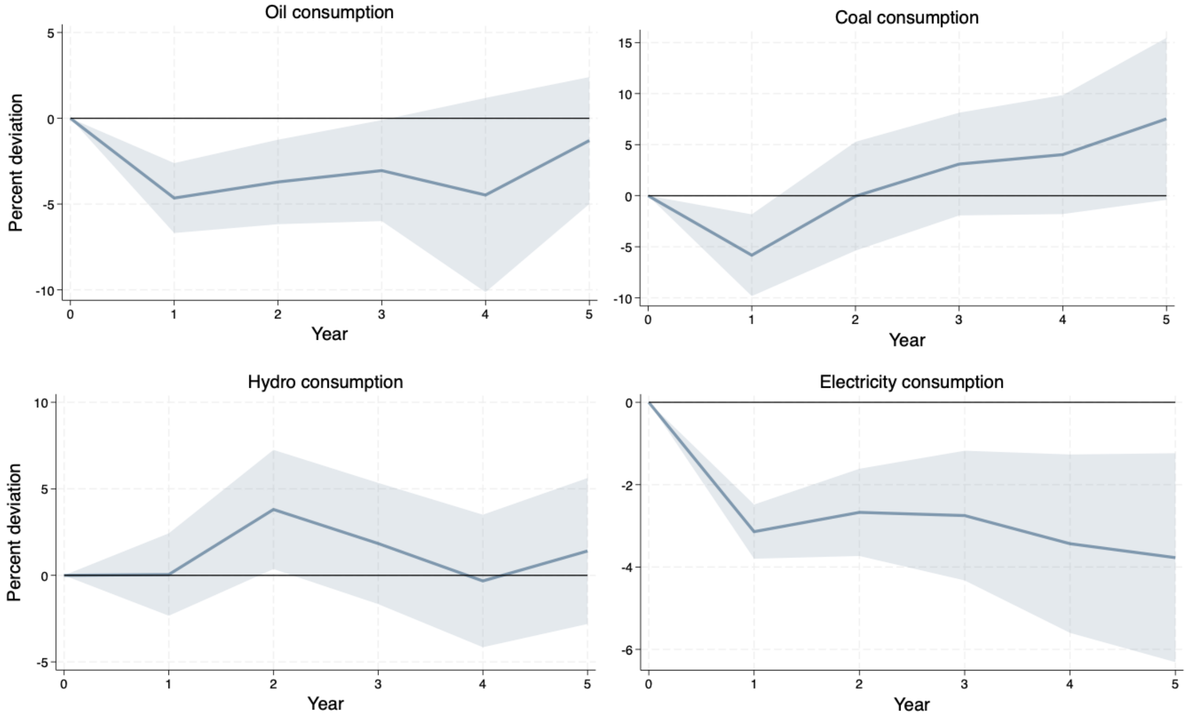
4.1. Baseline energy consumption results

We first examine the overall level of energy consumption in response to a recessionary shock to establish a baseline for our local projection model and assess how sensitive energy consumption is to economic shifts. Our results, based on equation (1), show a statistically significant decline of approximately 4 percent in electricity consumption in the medium term, or five years after a recession, which is characterized by an average 2.9 percent reduction in real GDP (Figure 1). This aligns with prior literature, such as the work by Jalles (2019) and Deb et al. (2023), which also observed a contraction in energy use following economic downturns.

We then analyzed the consumption of three primary energy inputs: oil, coal, and hydropower. Both oil and coal declined by about 5% in the first year after the shock. Coal showed a quicker recovery, reaching pre-recession levels by year three, consistent with studies on coal's flexibility in short-term energy management (Pryagyan, 2022). Oil's recovery was slower, with some uncertainty indicated by the confidence bands, making long-term conclusions difficult—echoing mixed findings on oil's elasticity to economic shocks (Hamilton, 2009). The recovery of fossil fuel consumption aligns with previous research showing the short-lived effects of recessions on fossil fuel use and CO_2 emissions (York, 2012; Peters et al., 2011). As the IMF suggests that recessions typically last about one year, we can infer the economy transitions into recovery by year two, with increasing industrial activity.

Importantly, hydropower stood out as the most resilient energy source, showing no significant deviations in any of the time horizons. This supports previous research indicating that renewable energy sources, particularly hydropower, tend to exhibit greater stability during economic downturns (Deb et al., 2023).

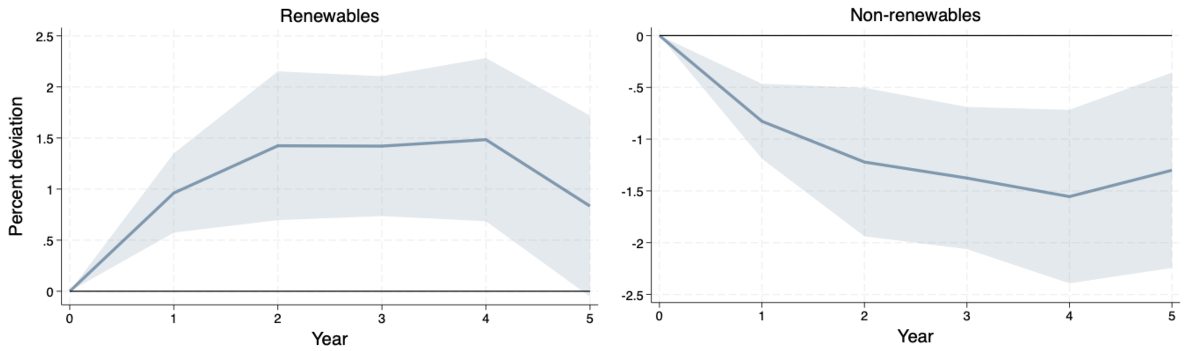
Figure 1: Local projections of energy consumption following a recession



Note: Local projections estimated on a sample of 74 countries over a 1982-2017 year range for oil and coal consumption, 138 countries for hydro, and 175 countries over a 1988 - 2017 year range for electricity consumption, using equation (1) with 90% confidence bands.

After aligning our baseline findings with prior research and setting the stage for a deeper exploration, it is important to view the fundamental differences between energy sources by examining transitions in the energy mix. To assess these transitions between renewable and non-renewable energy sources more comprehensively, we analyze their respective shares within total electricity consumption, rather than their individual levels of consumption. As shown in Figure 2, the baseline impulse response functions (IRFs) reveal a statistically significant increase of approximately 1.4 percentage points in the share of renewables, alongside a proportional decline in the share of non-renewable energy, in the short- to medium-term (2 to 4 years) following a recession, with these effects gradually reversing in the subsequent periods. The significance of our coefficients highlights the countercyclical nature of renewable energy adoption, a pattern also observed in previous studies (Deb et al., 2023; Rizwana et al., 2022; York, 2012; BP Statistical Review of World Energy, 2010). This finding reaffirms the validity of our baseline specifications before extending the analysis to the broader and more intricate dynamics of the business cycle.

Figure 2: Local projections of energy share response following a recession

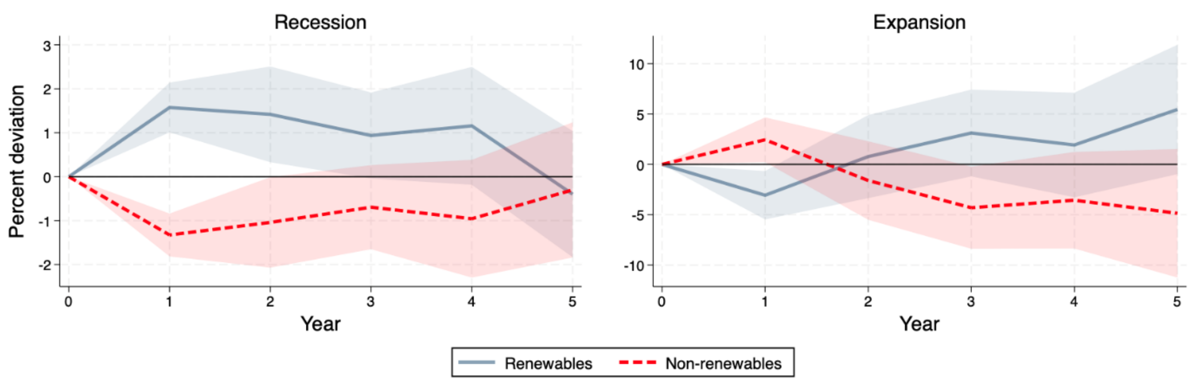


Note: Local projections estimated on a sample of 178 countries over a 1988 - 2018 year range, using equation (1) with 90% confidence bands.

5.2. Baseline STAR local projections

The previous section employed unconditional Local Projections (LPs), which may not fully capture the effects of the business cycle. From this point forward, the Impulse Response Functions (IRFs) are estimated using the conditional equation (2). When applying the conditional Smooth Transition Auto-Regressive (STAR) model to the overall country sample, we observed behaviour during recessions that was consistent with our baseline specifications.[3] Specifically, there was a statistically significant increase in renewable energy share and a proportional decrease in non-renewable share during the first and second years (Figure 3), although the significance of the shock dissipates in the following years. Conversely, during periods of economic expansion, we observe a significant short-term reduction of 2.4 percentage points in the renewable energy share in the first year, reversing in subsequent periods.

Figure 3: Local projections of energy mix during business cycles



Note: Local projections estimated on a sample of 178 countries over a 1988 - 2018 year range, using equation (2) with 90% confidence bands.

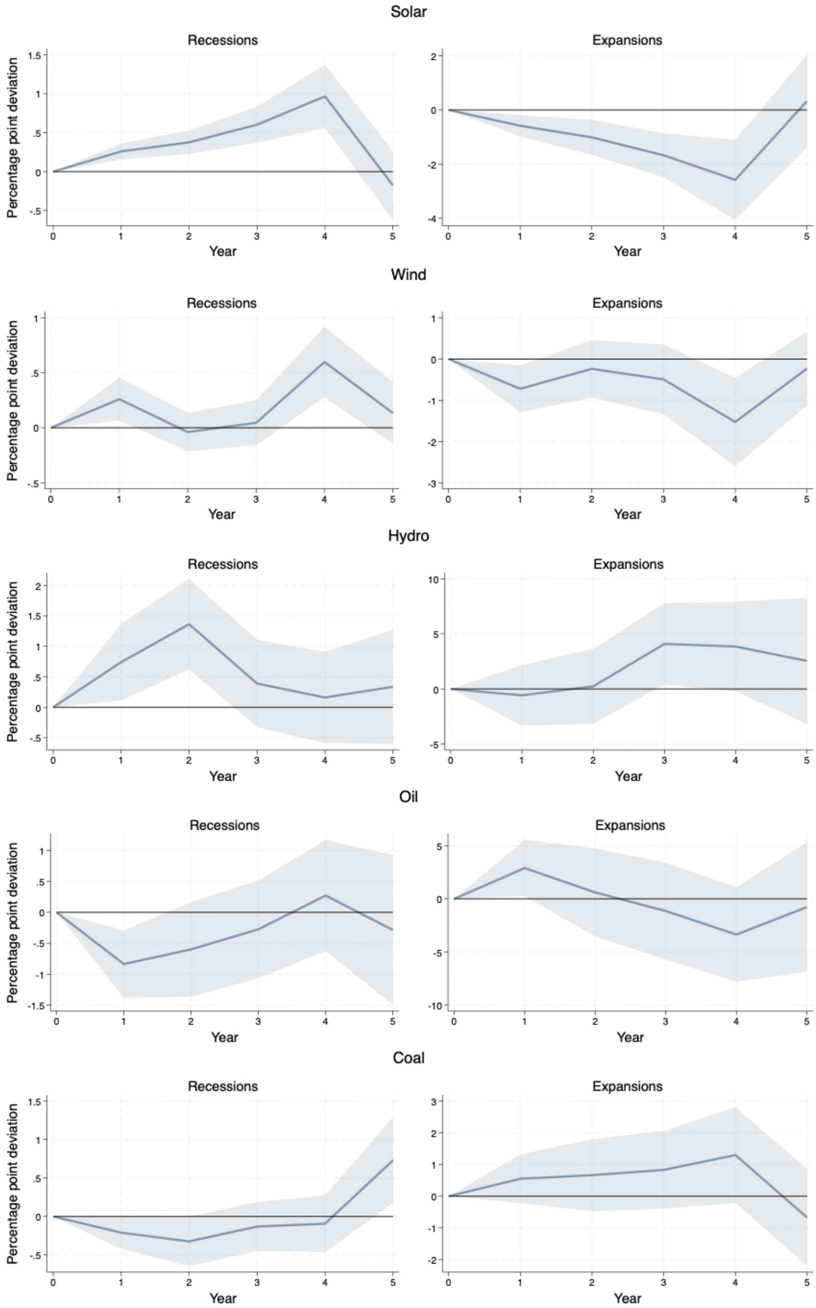
During economic expansions, there is typically a surge in energy demand due to increased industrial activity. This immediate rise often leads to a greater reliance on fossil fuels, as they

[3] Nonlinearities in the STAR model can produce larger coefficients, but they also tend to increase standard errors, especially when the transition between recession and expansion is gradual or not sharply defined.

can be ramped up quickly to meet short-term energy needs. In contrast, during recessions, industrial activity and overall energy demand decrease, allowing the relative share of renewable energy to appear more stable or even grow. This is due to lower incremental energy requirements, reduced production costs after infrastructure is built, and ongoing investments in renewable energy. The short-term effect of these dynamics stems from the nature of energy types: fossil fuels can be scaled up rapidly, while renewables generally require longer lead times for capacity expansion.

To highlight the distinct behaviors of various energy types, we estimated their individual impulse response functions (IRFs) (Figure 4). Wind energy showed sporadic but significant increases in the medium-to-long term, rising by 0.2-0.6 percentage points in total energy share, while solar energy increased by nearly 1 percentage point before declining. Hydroelectric power saw an immediate rise of 0.8-1.2 percentage points following recessions. During expansions, hydro use generally increased, though most coefficients were not statistically significant. In terms of level changes, solar and hydro showed no significant fluctuations, while wind energy was more sensitive to economic conditions (Appendix, Figure A1). This is understandable as solar energy, distributed from households to large-scale projects, tends to generate consistently after overcoming high installation costs. Wind energy, being more capital-intensive, is more responsive to business cycles. Hydroelectric power, despite high initial investments, is efficient and stable but may face limitations in meeting growing energy demand during economic expansions.

Figure 4: Local projections of energy types throughout business cycles



Note: Local projections estimated on a sample of 178 countries over a 1988 - 2018 year range, using equation (2) with 90% confidence bands.

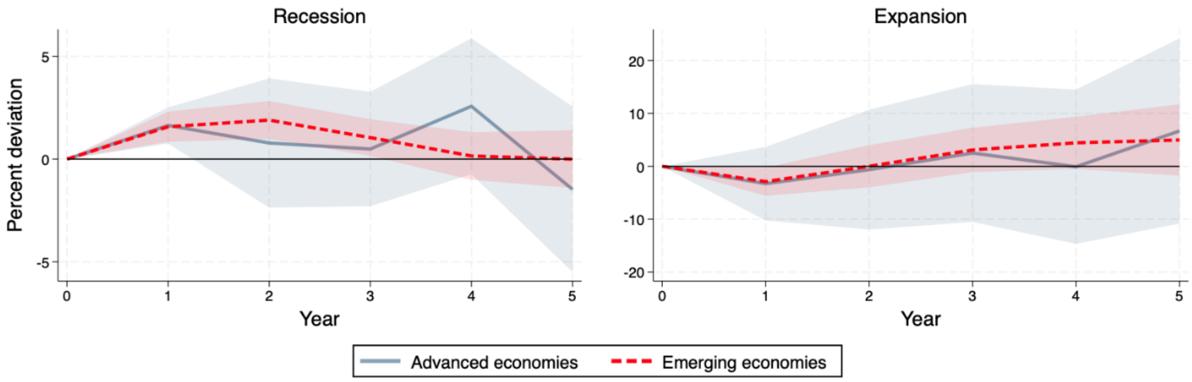
Turning to non-renewables, we see relatively high sensitivity to economic conditions, particularly for oil. As noted in our earlier analysis of consumption levels, cost-cutting becomes a priority during recessions, with fossil fuel use slump especially evident in emerging economies (see Appendix Figure A2). However, as the economy and energy demand recover, oil's competitive advantage returns due to its ease of scalability in the short term. Gas power, despite its increasing role as a lower-carbon alternative to oil and coal, showed no significant sensitivity to business cycle fluctuations. Coal, on the other hand, presents a unique case. After a slight initial decline in usage following a recession, coal consumption significantly increased by year five. Unlike other fossil fuels, coal has long been recognized as a low-cost and reliable source of energy, and its strengths are often accentuated during economic downturns. A key factor is that coal is predominantly sold through long-term supply contracts, ensuring steady demand for power generation. Contrasting many other commodities, primarily traded on spot markets and more susceptible to price volatility. Additionally, during a recession, countries may shift towards using domestically available resources, further boosting coal consumption in the medium term.

Thus, while the behaviour of different energy types follows general trends, their usage must be further contextualized within the economic structures of the countries they serve.

5.3. Impulse responses of renewables within economic groups

To further investigate the trajectory differences between economies, we performed comparative STAR regressions based on economic groups. We split our first IRFs into two categories—advanced and emerging economies (Figure 5). Both types of economies exhibit a similar immediate short-term shift towards renewables following a recession, with a statistically significant positive change. However, coefficients of expansion periods generally hovered around statistical insignificance. The key difference lies in the variance of these trajectories: advanced economies display much broader confidence intervals, indicating greater heterogeneity within this group. This is likely due to several factors, including more mature and diversified energy systems, well-established energy policy frameworks, higher levels of technological maturity, and diminishing returns on renewable energy investments. In contrast, emerging economies show a more consistent and significant shift towards renewables after a recession. These economies are typically in earlier stages of renewable adoption, where small policy changes or incremental investments can yield larger and more predictable gains. Although emerging markets face challenges like limited infrastructure and funding, their energy systems are less entrenched, allowing them to integrate renewable capacity more easily. The narrower confidence bands of emerging economies reflect their constrained choice set. Due to fewer available resources and strategies to cushion economic shocks, their energy transition tends to follow a more uniform trajectory. Mostly, the observed short-term shift towards renewables in emerging economies likely stems not from a surge in renewable energy output but rather from a sharp drop in fossil fuel use, coupled with relatively stable or slightly increasing renewable output. This highlights the structural limitations and opportunities that different economy types face in transitioning to greener energy sources.

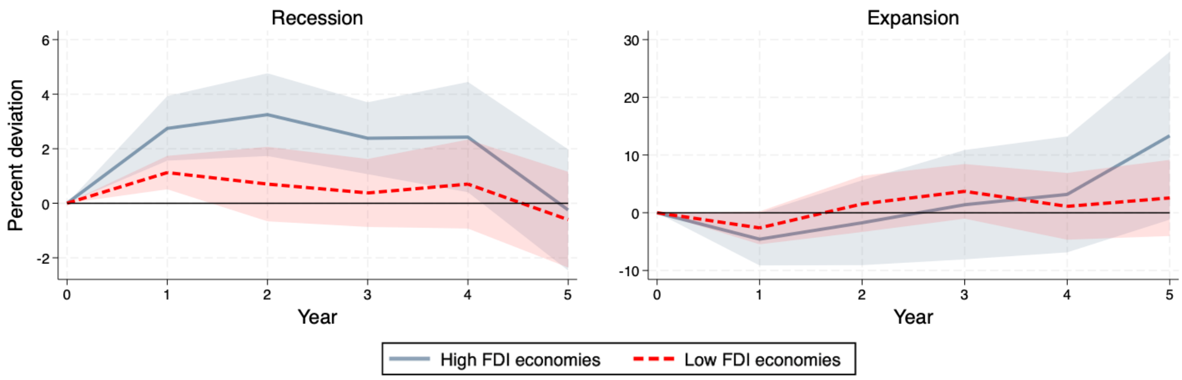
Figure 5: Local projections of advanced and emerging economies



Note: Local projections of advanced and emerging economies are estimated on a sample of 31 and 147 countries respectively, over a 1988 - 2018 year range, using equation (2) with 90 percent confidence bands.

Another dimension discussed in the literature is the role of foreign direct investment (FDI) in renewable energy adoption. We classified countries into two broad categories: those with FDI levels above the global mean ("high FDI economies") and those below it ("low FDI economies"). We further narrowed the scope for robustness.[4] The "high FDI economies" exhibited a substantial increase in renewable energy use, with a 2-3 percentage point rise sustained over four years following a recessionary shock. In contrast, "low FDI economies" showed only a modest 1 percentage point increase, which was concentrated in the first year (Figure 6). Expansion periods saw no significant differences for either group, though high FDI economies' trajectories were less constrained. Although not the sole determining factor, this stark contrast highlights the critical role that FDI plays in facilitating the transition to renewable energy, especially in capital-intensive infrastructure projects in the aftermath of downturns.

Figure 6: Local projections of high FDI and low FDI economies



Note: Local projections of high FDI and low FDI economies are estimated on a sample of 55 and 122 countries respectively, over a 1988 - 2018 year range, using equation (2) with 90 percent confidence bands.

To further test the role that FDI plays in renewable energy adoption, and to contribute to the often-conflicting research on this topic, we separated the FDI effects between advanced and emerging economies (Appendix Figure A4). A key distinction emerges. In advanced economies, foreign direct investment (FDI) complements existing domestic investment and

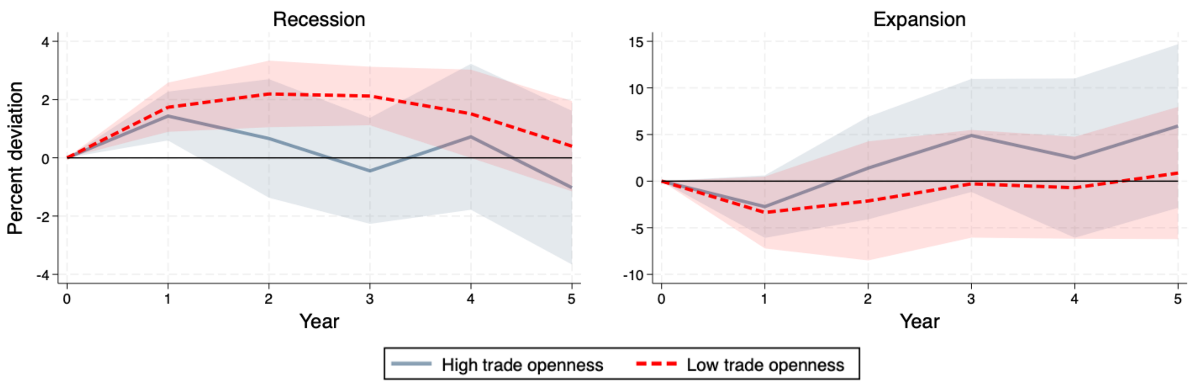
[4] We performed the estimations for upper 75th and lower 25th percentile economies in FDI, and found the magnitudes and statistical significance didn't change significantly (see Appendix Figure A3).

infrastructure of renewable energy projects, but effects on adoption were largely insignificant, apart from two outlier years, where we observed a positive impact during recessions and a slight negative impact during expansionary periods. In contrast, the distinctly insignificant IRF plots for emerging economies with low FDI highlight that the absence of both foreign and domestic capital severely limits the development of large-scale renewable energy projects, forcing greater reliance on fossil fuels and constraining their renewable energy transition during business cycles. This disparity shows the role that external financial support can play in bridging the investment gap in developing regions, where domestic resources are more limited, reinforcing the need for targeted policies that encourage FDI to support their energy transitions. While crucial, FDI encompasses broad investment across various sectors, including non-renewables, and only recently has there been a notable shift directing more FDI towards renewable infrastructure. Therefore, further refinements in estimations could focus on sector-specific FDI flows to assess the true impact on renewable energy adoption.

Turning to trade openness, we observe unique dynamics. Economies with lower trade openness—those more internally focused—exhibit far more consistent and statistically significant shifts towards renewable energy following recessions, contrasting with more open economies, where trade integration with global markets may dilute the effectiveness of domestic policies. However, neither group exhibited significant shifts during periods of economic expansion (see Figure 7).

One possibility for this difference is that more centralized and stable domestic policies, particularly following recessions, lead to more predictable, directed investments in renewable energy. In contrast, countries highly integrated into global supply chains tend to experience less consistent changes, as their exposure to the ebbs and flows of global markets dilutes the effects of domestic policies. This is particularly true for economies reliant on energy imports and foreign technologies. Distinguishing factor of low trade-to-GDP economies is their relatively large size, such as the USA and Japan, which possess diversified domestic markets capable of supplying most goods and services internally, thus generally less sensitive to global demand fluctuations. To further explore these dynamics, we divided the sample based on economic development (see Appendix Figure A5).

Figure 7: Local projections of economies with high trade openness and low trade openness



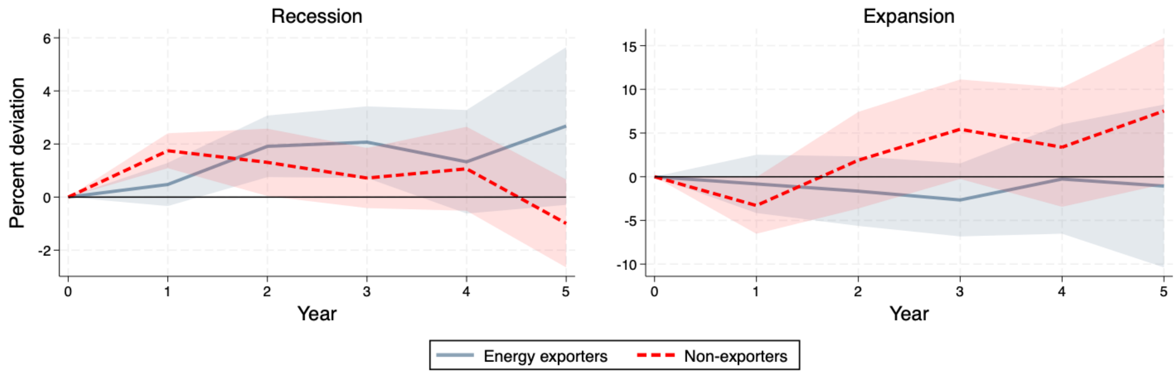
Note: Local projections of economies with high trade openness and low trade openness are estimated on a sample of 78 and 88 countries respectively, over a 1988 - 2018 year range, using equation (2) with 90 percent confidence bands.

The results displayed wider confidence bands in advanced economies highly exposed to global markets, reflecting their highly heterogeneous nature, whereas narrower bands in more self-reliant economies suggest an insulating effect. For emerging economies, the renewable adoption effect is marginally stronger in those with lower trade openness, but much of this effect during recessions is driven by reduced fossil fuel consumption rather than active adoption of renewables. In less globally connected economies reduction in fossil fuel imports is more pronounced, compared to more open economies that have easier access to global energy markets. To explore the strength of our findings, we performed IRF estimations on the extreme upper and lower 25% of economies in terms of trade openness. Advanced economies saw no difference with their baseline group. However, the most insulated emerging economies—those with a trade-to-GDP ratio of less than 50%, such as Brazil, Argentina, and India—now displayed insignificant renewable adoption (see Appendix Figure A6). This contrast suggests that trade openness alone does not fully explain differences in renewable adoption among the largest economies, and is likely due to specific internal policy measures, a point we will expand upon further.

Overall, our findings align with the short-term net-negative effect of trade openness on renewable adoption, observed by Zhang et al. (2021) and Murshed (2018). However, the inconclusive projections for expansions prevent us from confirming or rejecting the longer-term positive effects suggested by Alam and Murad (2020) and Thi et al. (2023). Further investigation into the energy-related import and export components of trade would provide additional insights.

To explore the energy trade dimension, we categorized countries as energy-exporting or non-exporting, following World Bank classifications. Non-exporters showed an immediate increase in renewable energy use during a recession, though this effect quickly faded (Figure 8). In contrast, energy-exporting countries exhibited no immediate response but saw a significant rise in renewable adoption—about 2 percentage points—in the second and third years of the recession. This suggests that entrenched energy infrastructures provide short-term resilience for energy-exporting nations, reducing the need for immediate renewable shifts. However, the delayed renewable adoption points to long-term diversification efforts. In their energy mix, hydro and wind increased in the medium term, while fossil fuels, particularly oil and coal, declined (Appendix, Figure A7). During expansions, oil consumption rebounded, reflecting the resilience of fossil fuels in energy-producing nations during periods of high demand, while also highlighting their vulnerability to price volatility during global downturns, offering a strategic opportunity for diversification.

Figure 8: Local projections of energy exporters and non-exporters

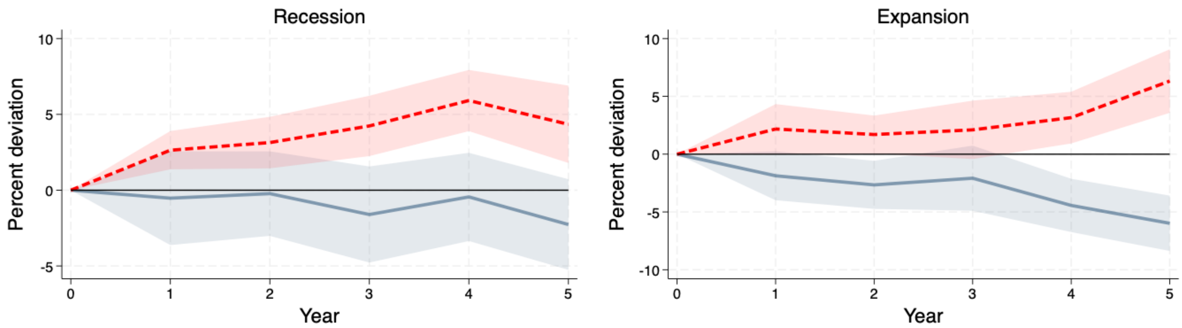


Note: Local projections of energy exporters and non-exporters are estimated on a sample of 35 and 143 countries respectively, over a 1988 - 2018 year range, using equation (2) with 90 percent confidence bands.

5.4. Environmental policy stringency effects

Before examining the effects of Environmental Policy Stringency (EPS), we needed to confirm if the baseline results hold for a smaller sample of 33 mainly OECD economies. Indeed, the findings were consistent—recessions led to an average 2 percent increase in renewable energy adoption. To test how EPS influences the renewable energy transition, we incorporated it as a variable in our STAR function. Here, it's important to note that we treated booms and busts separately, with expansions characterized as the first year of positive real GDP growth. While this approach trades off accounting for the magnitude of recessions or expansions, the consistency of our baseline results in the unconditional and conditional STAR functions suggests that this framework remains robust.

Figure 9: Local projections of environmental policy stringency

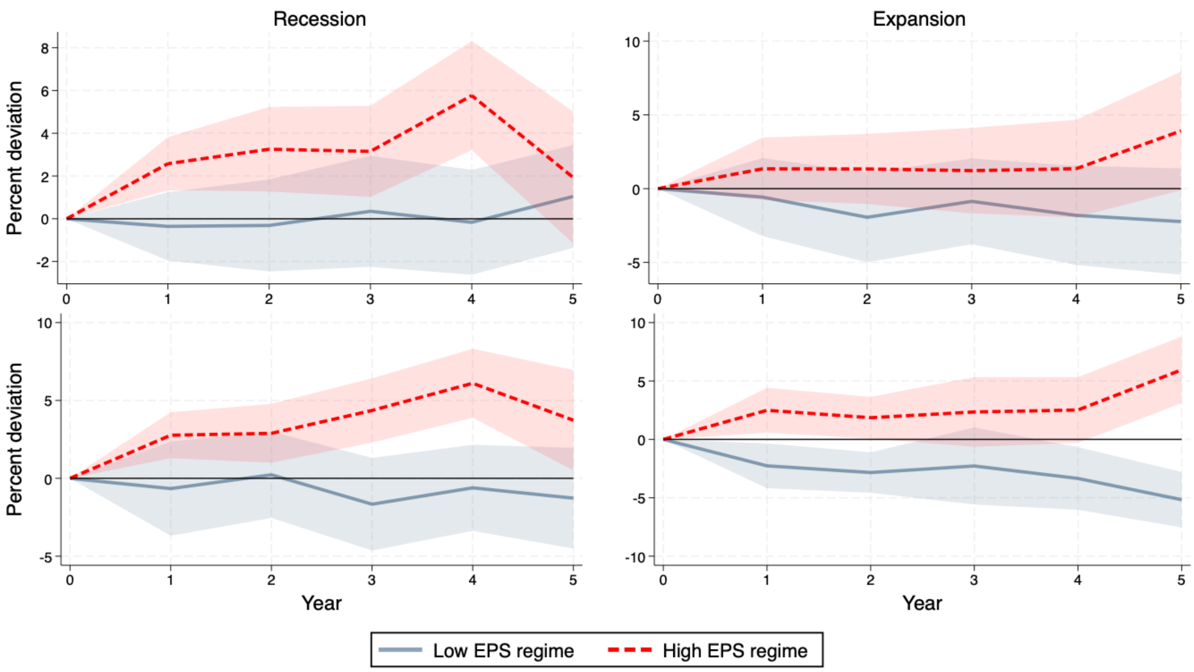


Note: Local projections estimated on a sample of 32 countries over a 1993 - 2018 year range, using equation (2) with 90 percent confidence bands.

The results indicate that policy stringency is a crucial factor in mediating energy transitions. In both recessions and expansions, high EPS regimes significantly boosted renewable adoption. During recessions, this shift was immediate and sustained throughout all horizons, while in expansions, renewable adoption reached significance in the later horizons. Conversely, in low EPS regimes, renewables showed no statistically significant changes following recessions, while expansions led to a reduction in their adoption (see Figure 9).

To delve further into the analysis, we separated the EPS index into market-based and non-market-based (conventional) policies (see Figure 10).[5] Both policy types had a significant and positive effect on renewable adoption following recessions, aligning with the findings of Deb et al. (2023). Low-stringency regimes showed no significant changes in renewable adoption. However, during expansions, we observed a notable divergence: market-based policies exhibited no significant effect, whereas non-market-based policies showed opposite but equally significant outcomes. High EPS regimes saw a 6 percent increase in renewable adoption, while low EPS regimes experienced a 5 percent decrease, a distinction in long-term policy effectiveness supported by the findings of Zhang et al. (2022).

Figure 10: Local projections of EPS market-based policies and EPS index non-market-based policies



Note: Local projections estimated on a sample of 32 countries over a 1993 - 2018 year range, using equation (2) with 90 percent confidence bands. Top chart covers market-based policies while the bottom chart covers non-market-based policies.

The distinction between market-based and non-market-based policies is logical. Market-based policies, like carbon trading and pollution taxes, impose costs that push firms toward renewables, especially during recessions when cost-cutting is critical. Renewables, with lower operational costs once installed, become more appealing in slower economic periods. During booms, however, firms focus on expansion and profitability, making fossil fuels more attractive and reducing the impact of market-based policies. Non-market-based policies, such as R&D incentives and regulatory standards, maintain influence across business cycles since they mandate compliance regardless of economic conditions. Countries with strong non-market-based policies, like Germany and Denmark, have seen continuous renewable growth, while those reliant on market-based systems, such as the EU's Emissions Trading System (ETS), experience more cyclical adoption. China, with strict conventional policies, increased its

[5] Market-based policies: feed-in-tariffs, taxes on pollutants, carbon trading, energy and green trading certificates. Non-market-based: public investment, R&D incentives and investments, emission and fuel standards.

renewable share from 11.9% to 22% between 1990 and 2023, while weaker-policy countries like Brazil and Indonesia have seen declines. This underscores the critical role of robust environmental policies, particularly in advanced economies, in driving renewable energy adoption across business cycles.

7. Conclusion and Policy Implications

This paper provides key insights into the short- to medium-term dynamics of renewable energy adoption across 178 economies, highlighting how energy transitions evolve through business cycles. The findings confirm the countercyclical nature of renewable energy adoption, with recessions driving a medium-term increase in renewables, while economic expansions temporarily slow this trend. Renewables like solar, wind, and hydro demonstrate resilience during downturns, while fossil fuels regain prominence during recoveries due to their scalability.

Emerging economies, particularly those with higher foreign direct investment (FDI), showed stronger shifts toward renewables following recessions, while advanced economies exhibited more varied responses. Trade-dependent economies struggled to maintain renewable adoption during downturns, while energy-exporting countries diversified into renewables in recessions but reversed this trend during booms.

Environmental policy stringency (EPS) emerged as a critical factor, with high-EPS economies more likely to adopt renewables throughout business cycles. Market-based and conventional policies supported renewable adoption during recessions, though only conventional policies significantly boosted it during expansions.

Policy recommendations include adopting countercyclical measures to promote renewables during recessions, targeting FDI toward green infrastructure in emerging economies, and using fossil fuel revenues in energy-exporting countries to support renewable transitions. Future research should further explore phases within expansions, different economic shocks, and long-term impacts.

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Appendix

Table A1. FIXED EFFECT MODEL COMPARISONS

	Recession impact on total renewable share		
	(1)	(2)	(3)
VARIABLES	OLS	Fixed Effects	Fixed Effects
Recession	-0.0236	0.0189***	0.00701
	(0.0156)	(0.00460)	(0.00427)
Constant	0.346***	0.342***	0.340***
	(0.00510)	(0.000456)	(0.0183)
Observations	4,654	4,654	4,654
R-squared	0.000	0.004	0.062
Number of ifscode		179	179
Country FE		YES	YES
Year FE			YES

Robust standard errors in parentheses:
*** p<0.01 ** p<0.05 * p<0.1

Table A2: UNIT ROOT TESTS

Variables	Augmented Dickey-Fuller (ADF) test			
	Level p-value		First difference p-value	
	Constant	Constant + trend	Constant	Constant + trend
Real GDP growth	0.000	0.000	None	None
EPS	1.000	1.000	0.000	0.000
Energy consumption (ln)				
Oil	0.000	0.000	None	None
Coal	1.000	1.000	0.000	0.000
Hydro	0.000	0.000	None	None
Electricity	0.891	1.000	0.000	0.000
Share in total electricity				
Renewables	1.000	0.990	0.000	0.000
Solar	1.000	1.000	0.008	0.000
Hydro	0.002	0.001	0.000	0.000
Wind	1.000	1.000	0.000	0.000
Nuclear	0.977	0.627	0.000	0.000
Bioenergy	1.000	1.000	0.000	0.000
Other renewables	1.000	0.243	0.000	0.000
Non-renewables	1.000	1.000	0.000	0.000
Oil	0.274	0.404	0.000	0.000
Coal	1.000	0.984	0.000	0.000
Gas	0.979	0.968	0.000	0.000

None = indicates that the variable was already stationary in the level, and therefore does not need to be tested on the first difference

Table A3: DESCRIPTIVE STATISTICS

VARIABLE	**Overall**			AEs			EMs			Energy exporters			Upper FDI			Upper TO			Upper EPS			Scope	Source
	Obs	Mean	S.D.	Obs	Mean	S.D.	Obs	Mean	S.D.	Obs	Mean	S.D.	Obs	Mean	S.D.	Obs	Mean	S.D.	Obs	Mean	S.D.		
Energy consumption (level)																							
Coal	3711	3.39	2.80	562	4.16	2.57	3149	3.25	2.81	806	3.27	2.97	901	3.11	2.91	1500	3.03	2.87	328	3.66	2.88	1965-2022	OurWorld in Data
Oil	3985	5.04	1.49	616	4.89	1.14	3369	5.06	1.55	819	5.06	1.36	884	4.72	1.40	1551	4.78	1.34	346	4.73	0.90	1965-2022	OurWorld in Data
Electricity	5107	2.56	2.47	1266	4.08	1.83	3841	2.06	2.46	1042	3.17	1.87	1405	1.45	2.10	2187	1.88	2.17	684	4.78	1.37	1985-2022	OurWorld in Data
Energy consumption (share)																							
Renewables	4811	33.7%	32.8%	1099	40.1%	31.1%	3689	32.0%	33.1%	872	27.5%	31.3%	1423	25.2%	29.7%	2081	28.0%	30.8%	618	45.2%	30.1%	1985-2022	OurWorld in Data
Wind	4811	1.4%	4.4%	1099	3.7%	7.6%	3689	0.7%	2.5%	872	0.2%	0.9%	1423	1.8%	5.3%	2081	1.4%	5.2%	618	3.8%	7.4%	1985-2022	OurWorld in Data
Solar	4811	0.7%	2.4%	1099	1.1%	2.8%	3689	0.6%	2.1%	872	0.2%	1.4%	1423	0.8%	2.3%	2081	0.8%	2.9%	618	1.1%	2.4%	1985-2022	OurWorld in Data
Nuclear	4811	4.6%	12.4%	1099	14.2%	20.4%	3689	1.7%	6.4%	872	1.2%	3.8%	1423	1.6%	7.0%	2081	4.8%	13.7%	618	18.6%	20.8%	1985-2022	OurWorld in Data
Hydro	4811	24.7%	30.6%	1099	17.5%	24.6%	3689	27.0%	31.9%	872	25.5%	30.5%	1423	19.2%	28.3%	2081	18.7%	27.8%	618	18.7%	26.5%	1985-2022	OurWorld in Data
Bioenergy	4811	1.7%	5.3%	1099	2.7%	4.3%	3689	1.4%	5.6%	872	0.4%	0.9%	1423	1.4%	3.5%	2081	2.1%	7.3%	618	3.1%	3.9%	1985-2022	OurWorld in Data
Other renewables	4811	0.7%	3.8%	1099	0.9%	4.2%	3689	0.7%	3.7%	872	0.1%	0.5%	1423	0.4%	2.3%	2081	0.1%	0.9%	618	0.1%	0.4%	1985-2022	OurWorld in Data
Non-renewables	4811	56.5%	32.2%	1099	45.3%	26.8%	3689	59.6%	32.9%	872	67.9%	32.2%	1423	66.5%	30.9%	2081	63.2%	31.9%	618	40.1%	24.4%	1985-2022	OurWorld in Data
Oil	4811	28.2%	36.5%	1099	15.0%	27.6%	3689	31.6%	37.6%	872	19.8%	29.1%	1423	47.6%	43.0%	2081	32.1%	39.7%	618	11.1%	22.0%	1985-2022	OurWorld in Data
Gas	4811	18.5%	27.9%	1099	15.6%	17.3%	3689	19.5%	30.4%	872	43.4%	36.6%	1423	10.5%	20.5%	2081	22.2%	32.3%	618	14.4%	13.6%	1985-2022	OurWorld in Data
Coal	4811	9.8%	14.6%	1099	14.6%	13.7%	3689	8.4%	14.6%	872	4.7%	10.5%	1423	8.3%	14.1%	2081	8.8%	14.4%	618	14.6%	11.5%	1985-2022	OurWorld in Data
Economic data																							
Real annual GDP growth	7473	3.4%	6.2%	1385	2.7%	3.4%	6089	3.5%	6.7%	1365	3.6%	9.7%	2274	3.8%	7.3%	3204	3.5%	7.2%	791	2.2%	2.8%	1980-2022	IMF, World Economic Outlook Database
Recession*	7473	0.10	0.31	1385	0.09	0.29	6088	0.11	0.31	1364	0.11	0.32	2274	0.11	0.31	3204	0.11	0.31	791	0.09	0.29	1980-2022	Own calculations
Environmental policy stringency (EPS)**	1023	1.92	1.15	744	2.23	1.06	279	1.12	0.99	124	1.41	1.20	186	2.31	1.05	341	2.12	1.08	558	2.41	1.04	1990-2020	OECD, EPS index dataset
Trade openness (TO)***	7812	76.63	48.67	1668	95.17	73.86	6115	71.57	37.68	1408	72.81	33.54	2073	100.12	60.54	3235	113.74	52.72	928	73.19	33.44	1965-2022	IMF, World Economic Outlook Database
Foreign direct investment (FDI)****	1946	3.89	15.22	365	5.51	32.89	1571	3.53	5.94	351	1.94	5.09	607	8.80	17.20	860	4.88	22.37	196	3.40	12.68	1990-2022	OurWorld in Data

*A dummy variable of 1 during the first year of negative real GDP growth and 0 otherwise.

**Index ranking from 0 (no stringency) to 6 (very stringent).

***The ratio of exports + imports over GDP.

****Net inflows (% of GDP)

Table A4. Regression results underlying Figure 1.

	Energy consumption (level) following recessions			
Horizon	Electricity	Coal	Oil	Hydro
1 year	-0.0314***	-0.0583*	-0.0472***	0.000466
	(0.0045)	(0.0243)	(0.0122)	(0.0145)
2 years	-0.0274***	-0.000481	-0.0392*	0.0381
	(0.0066)	(0.0324)	(0.0157)	(0.0209)
3 years	-0.0285**	0.031	-0.032	0.0184
	(0.0089)	(0.0306)	(0.0191)	(0.0213)
4 years	-0.0378**	0.0403	-0.0457	-0.00325
	(0.0116)	(0.0354)	(0.0352)	(0.0233)
5 years	-0.0389*	0.0753	-0.0131	0.0141
	(0.0151)	(0.0482)	(0.0172)	(0.0256)

Standard errors in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A5. Regression results underlying Figure 2.

	Energy mix following recessions	
Horizon	Renewables	Non-renewables
1 year	0.00962***	-0.00828***
	(0.0024)	(0.0022)
2 years	0.0142**	-0.0122**
	(0.0044)	(0.0044)
3 years	0.0142***	-0.0138**
	(0.0042)	(0.0042)
4 years	0.0148**	-0.0155**
	(0.0049)	(0.0051)
5 years	0.00833	-0.0130*
	(0.0054)	(0.0057)

Standard errors in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A6. Regression results underlying Figure 3.

	Energy mix during business cycles			
	Renewables		Non-renewables	
Horizon	Recession	Expansion	Recession	Expansion
1 year	0.0157***	-0.0306*	-0.0133***	0.0244
	(0.0034)	(0.0146)	(0.0030)	(0.0135)
2 years	0.0142*	0.00773	-0.0104	-0.0160
	(0.0066)	(0.0250)	(0.0063)	(0.0237)
3 years	0.00937	0.0312	-0.00694	-0.0430
	(0.0059)	(0.0262)	(0.0058)	(0.0248)
4 years	0.0116	0.0193	-0.00956	-0.0356
	(0.0081)	(0.0315)	(0.0081)	(0.0291)
5 years	-0.00398	0.0546	-0.00301	-0.0486
	(0.0087)	(0.0390)	(0.0094)	(0.0388)

Standard errors in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A7. Regression results underlying Figure 4.

	Energy types during business cycles					
	Hydro		Wind		Solar	
Horizon	Recession	Expansion	Recession	Expansion	Recession	Expansion
1 year	0.00741*	-0.00583	0.00260*	-0.00721*	0.00259***	-0.00583*
	(0.00381)	(0.0167)	(0.00118)	(0.00345)	(0.000637)	(0.00239)
2 years	0.0136**	0.00236	-0.000388	-0.00238	0.00376***	-0.0101*
	(0.00452)	(0.0207)	(0.00106)	(0.00424)	(0.000917)	(0.00392)
3 years	0.00390	0.0409	0.000449	-0.00493	0.00602***	-0.017***
	(0.00435)	(0.0225)	(0.00124)	(0.00514)	(0.00141)	(0.00493)
4 years	0.00161	0.0385	0.00598**	-0.0153*	0.00966***	-0.0258**
	(0.00454)	(0.0248)	(0.00195)	(0.00652)	(0.00247)	(0.00895)
5 years	0.00336	0.0255	0.00133	-0.00232	-0.00177	0.00327
	(0.00570)	(0.0348)	(0.00171)	(0.00546)	(0.00268)	(0.0104)
	Coal		Oil (overall)		Oil (emerging markets)	
Horizon	Recession	Expansion	Recession	Expansion	Recession	Expansion
1 year	-0.00210	0.00551	-0.00837*	0.0290	-0.0116*	0.0414*
	(0.00128)	(0.00464)	(0.00330)	(0.0161)	(0.00448)	(0.0191)
2 years	-0.00324	0.00665	-0.00599	0.00604	-0.0114	0.0217
	(0.00195)	(0.00687)	(0.00465)	(0.0252)	(0.00618)	(0.0286)
3 years	-0.00131	0.00831	-0.00274	-0.0114	-0.00800	0.000008
	(0.00193)	(0.00744)	(0.00480)	(0.0277)	(0.00618)	(0.0319)
4 years	-0.000940	0.0130	0.00273	-0.0337	-0.00257	-0.0203
	(0.00225)	(0.00916)	(0.00546)	(0.0270)	(0.00655)	(0.0309)
5 years	0.00731*	-0.00673	-0.00285	-0.00770	-0.00886	-0.000596
	(0.00339)	(0.00928)	(0.00736)	(0.0371)	(0.0101)	(0.0441)

Standard errors in parentheses: * p < 0.05, ** p < 0.01, *** p < 0.001

Table A8. Regression results underlying Figure 5.

	Renewables			
	Emerging economies		Advanced economies	
Horizon	Recession	Expansion	Recession	Expansion
1 year	0.0158***	-0.0290	0.0164**	-0.0328
	(0.00444)	(0.0162)	(0.00533)	(0.0422)
2 years	0.0190***	0.000099	0.00784	-0.00634
	(0.00560)	(0.0241)	(0.0191)	(0.0688)
3 years	0.0105	0.0310	0.00492	0.0251
	(0.00541)	(0.0254)	(0.0169)	(0.0792)
4 years	0.00154	0.0444	0.0257	-0.000825
	(0.00703)	(0.0299)	(0.0201)	(0.0885)
5 years	-0.000027	0.0498	-0.0147	0.0668
	(0.00852)	(0.0410)	(0.0245)	(0.106)

Standard errors in parentheses: * p < 0.05, ** p < 0.01, *** p < 0.001

Table A9. Regression results underlying Figure 6.

	Renewables			
	Low FDI		High FDI	
Horizon	Recession	Expansion	Recession	Expansion
1 year	0.0113**	-0.0262	0.0275***	-0.0458
	(0.00371)	(0.0173)	(0.00719)	(0.0276)
2 years	0.00704	0.0154	0.0325***	-0.0173
	(0.00830)	(0.0296)	(0.00921)	(0.0447)
3 years	0.00378	0.0371	0.0239**	0.0139
	(0.00757)	(0.0288)	(0.00800)	(0.0576)
4 years	0.00704	0.0111	0.0243	0.0318
	(0.00991)	(0.0351)	(0.0123)	(0.0610)
5 years	-0.00603	0.0257	-0.00245	0.133
	(0.0107)	(0.0401)	(0.0135)	(0.0883)

Standard errors in parentheses: * p < 0.05, ** p < 0.01, *** p < 0.001

Table A10. Regression results underlying Figure 7.

	Renewables							
	Advanced economies				Emerging economies			
	Low FDI		High FDI		Low FDI		High FDI	
Horizon	Recession	Expansion	Recession	Expansion	Recession	Expansion	Recession	Expansion
1 year	0.0154*	-0.0385	0.0126	0.0443	0.00895	-0.0184	0.0315***	-0.0577
	(0.00652)	(0.0475)	(0.0104)	(0.112)	(0.00466)	(0.0189)	(0.00895)	(0.0310)
2 years	0.00462	-0.00505	0.0194	-0.0103	0.0103	0.0124	0.0391***	-0.0362
	(0.0234)	(0.0797)	(0.0135)	(0.116)	(0.00578)	(0.0267)	(0.0111)	(0.0477)
3 years	-0.00133	0.0592	0.0304	-0.150	0.00538	0.0322	0.0231*	0.0207
	(0.0210)	(0.0947)	(0.0162)	(0.153)	(0.00633)	(0.0248)	(0.00966)	(0.0607)
4 years	0.0120	0.0489	0.0782**	-0.260	0.00150	0.0168	0.000935	0.105
	(0.0246)	(0.109)	(0.0146)	(0.131)	(0.00835)	(0.0311)	(0.0126)	(0.0598)
5 years	-0.0216	0.107	0.0117	-0.107	-0.00137	0.0110	-0.00261	0.149
	(0.0304)	(0.128)	(0.0225)	(0.182)	(0.00978)	(0.0390)	(0.0166)	(0.0958)

Standard errors in parentheses: * p < 0.05, ** p < 0.01, *** p < 0.001

Table A11. Regression results underlying Figure 8.

	Renewables			
	Low trade openness		High trade openness	
Horizon	Recession	Expansion	Recession	Expansion
1 year	0.0174**	-0.0336	0.0143**	-0.0274
	(0.00513)	(0.0234)	(0.00509)	(0.0204)
2 years	0.0219**	-0.0212	0.00664	0.0140
	(0.00694)	(0.0388)	(0.0124)	(0.0334)
3 years	0.0212***	-0.00287	-0.00447	0.0490
	(0.00610)	(0.0351)	(0.0111)	(0.0368)
4 years	0.0151	-0.00709	0.00722	0.0247
	(0.00921)	(0.0332)	(0.0152)	(0.0519)
5 years	0.00399	0.00868	-0.0102	0.0591
	(0.00942)	(0.0431)	(0.0160)	(0.0533)

Standard errors in parentheses: * p < 0.05, ** p < 0.01, *** p < 0.001

Table A12. Regression results underlying Figure 9.

	Renewables							
	Advanced economies				Emerging economies			
	Low trade openness		High trade openness		Low trade openness		High trade openness	
Horizon	Recession	Expansion	Recession	Expansion	Recession	Expansion	Recession	Expansion
1 year	0.0229*	-0.0418	0.0139	-0.0642	0.0167*	-0.0355	0.0148*	-0.0232
	(0.00827)	(0.0398)	(0.0101)	(0.118)	(0.00750)	(0.0299)	(0.00597)	(0.0204)
2 years	0.0274	-0.0554	-0.0198	0.0558	0.0203*	-0.0148	0.0190*	-0.0118
	(0.0136)	(0.0645)	(0.0450)	(0.180)	(0.00828)	(0.0446)	(0.00820)	(0.0252)
3 years	0.0189	-0.0151	-0.0134	0.0828	0.0206*	-0.000027	-0.000071	0.0402
	(0.0104)	(0.0566)	(0.0439)	(0.245)	(0.00817)	(0.0418)	(0.00779)	(0.0278)
4 years	0.0408*	-0.0577	0.0133	0.100	-0.00145	0.0282	0.00283	0.0346
	(0.0190)	(0.0525)	(0.0449)	(0.254)	(0.00999)	(0.0394)	(0.0110)	(0.0397)
5 years	0.00566	0.0251	-0.0291	0.0958	0.00352	-0.00178	-0.000427	0.0436
	(0.0157)	(0.0576)	(0.0603)	(0.370)	(0.0124)	(0.0545)	(0.0136)	(0.0449)

Standard errors in parentheses: * p < 0.05, ** p < 0.01, *** p < 0.001

Table A13. Regression results underlying Figure 10.

	Renewables			
	Energy exporters		Non-exporters	
Horizon	Recession	Expansion	Recession	Expansion
1 year	0.00476	-0.00821	0.0175***	-0.0329
	(0.00494)	(0.0202)	(0.00399)	(0.0197)
2 years	0.0191*	-0.0165	0.0131	0.0189
	(0.00704)	(0.0241)	(0.00771)	(0.0336)
3 years	0.0207*	-0.0266	0.00718	0.0544
	(0.00819)	(0.0254)	(0.00688)	(0.0346)
4 years	0.0133	-0.00263	0.0107	0.0338
	(0.0118)	(0.0380)	(0.00961)	(0.0414)
5 years	0.0268	-0.0106	-0.00994	0.0752
	(0.0180)	(0.0566)	(0.0101)	(0.0509)

Standard errors in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A14. Regression results underlying Figure 11.

	Renewables			
	Low EPS		High EPS	
Horizon	Recession	Expansion	Recession	Expansion
1 year	-0.00526	-0.0187	0.0264**	0.0218
	(0.0188)	(0.0128)	(0.00766)	(0.0131)
2 years	-0.00225	-0.0266*	0.0314**	0.0170
	(0.0169)	(0.0126)	(0.0103)	(0.00995)
3 years	-0.0160	-0.0208	0.0424**	0.0210
	(0.0192)	(0.0171)	(0.0121)	(0.0153)
4 years	-0.00443	-0.0443**	0.0591***	0.0316*
	(0.0177)	(0.0140)	(0.0123)	(0.0136)
5 years	-0.0226	-0.0598***	0.0435**	0.0632***
	(0.0181)	(0.0145)	(0.0155)	(0.0167)

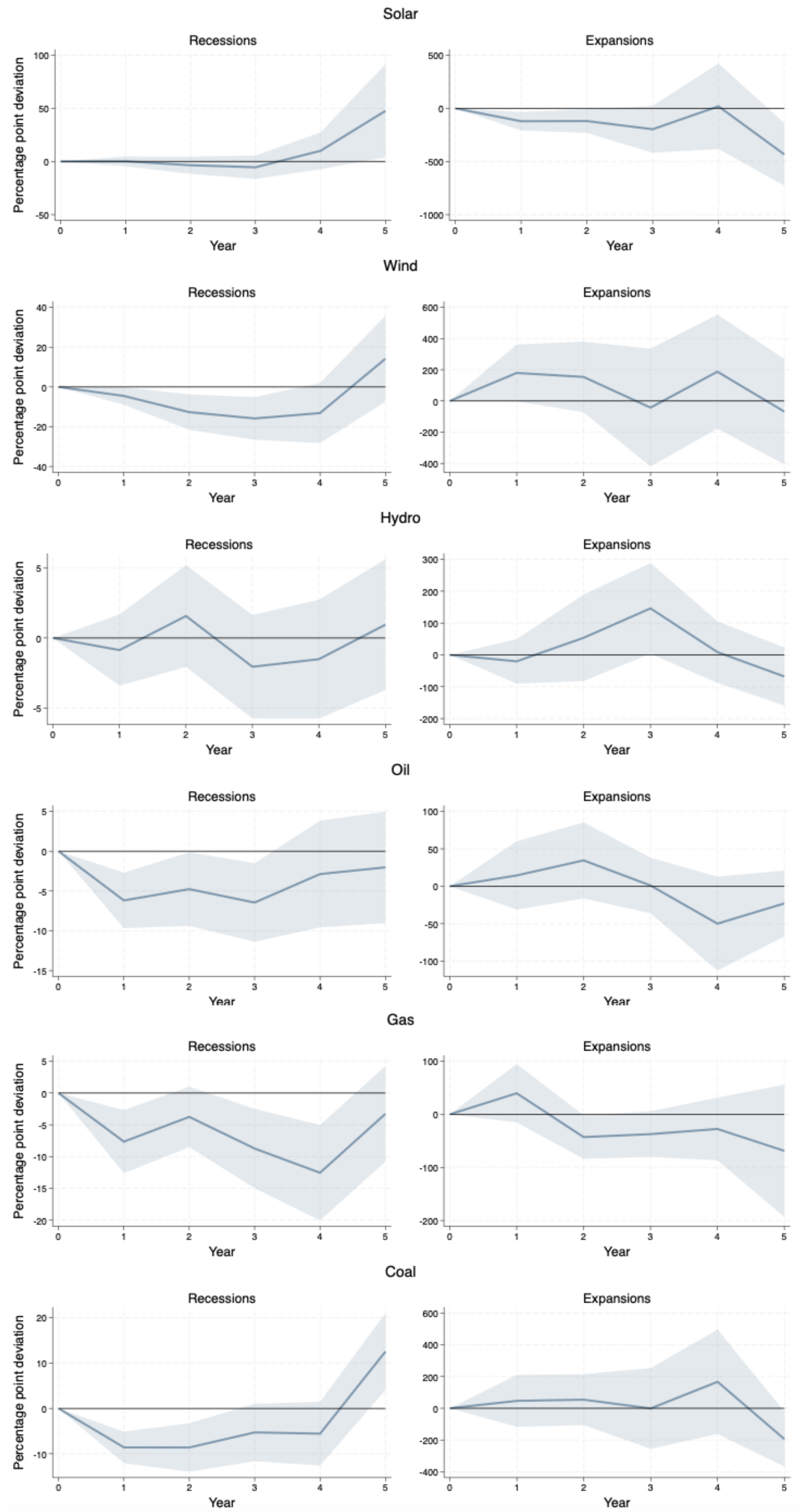
Standard errors in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A15. Regression results underlying Figure 12.

	Renewables							
	Market-based policies				Non-market-based policies			
	Low EPS		High EPS		Low EPS		High EPS	
Horizon	Recession	Expansion	Recession	Expansion	Recession	Expansion	Recession	Expansion
1 year	-0.00355	-0.00569	0.0258**	0.0134	-0.00659	-0.0226	0.0277**	0.0249*
	(0.00971)	(0.0161)	(0.00755)	(0.0129)	(0.0184)	(0.0116)	(0.00895)	(0.0116)
2 years	-0.00311	-0.0194	0.0325*	0.0134	0.00228	-0.0284*	0.0289*	0.0186
	(0.0131)	(0.0185)	(0.0120)	(0.0144)	(0.0168)	(0.0105)	(0.0115)	(0.0108)
3 years	0.00350	-0.00859	0.0315*	0.0122	-0.0166	-0.0228	0.0436**	0.0235
	(0.0158)	(0.0176)	(0.0129)	(0.0176)	(0.0181)	(0.0200)	(0.0125)	(0.0181)
4 years	-0.00165	-0.0181	0.0576***	0.0136	-0.00608	-0.0334*	0.0610***	0.0252
	(0.0149)	(0.0204)	(0.0155)	(0.0201)	(0.0168)	(0.0163)	(0.0134)	(0.0171)
5 years	0.0104	-0.0223	0.0194	0.0391	-0.0127	-0.0516**	0.0373	0.0596**
	(0.0146)	(0.0219)	(0.0187)	(0.0244)	(0.0197)	(0.0144)	(0.0196)	(0.0173)

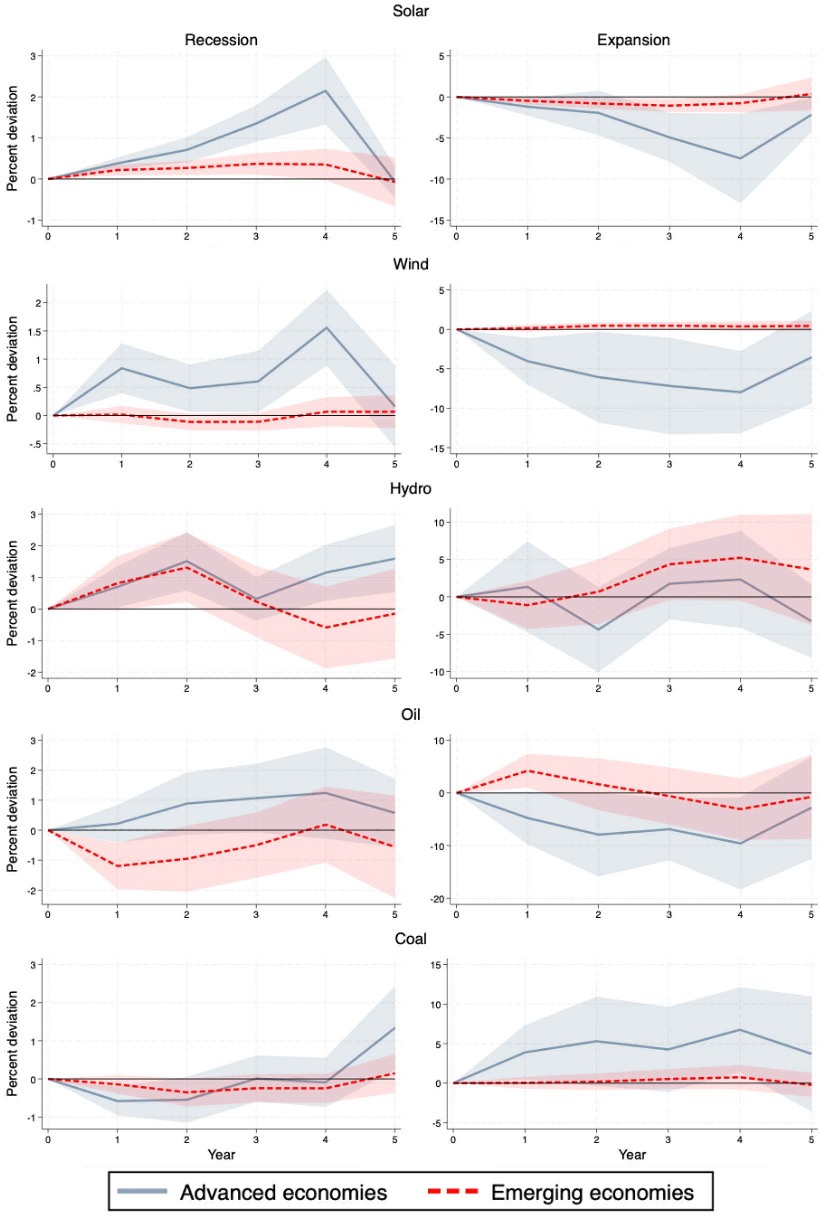
Standard errors in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure A1. Level Changes in energy consumption during business cycles



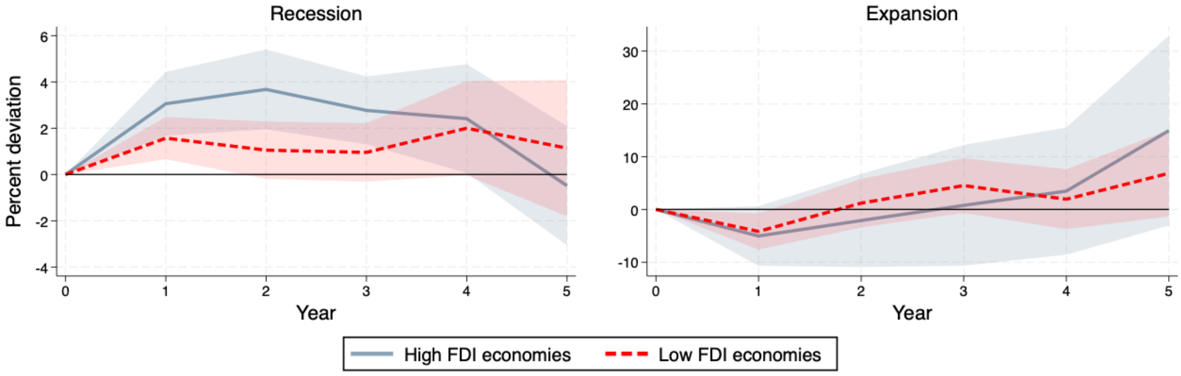
Note: Local projections estimated on a sample of 178 countries over a 1988 - 2018 year range, using equation (2) with 90% confidence bands. Other energy types were statistically insignificant.

Figure A2: Energy mix during business cycles (advanced vs emerging economies)



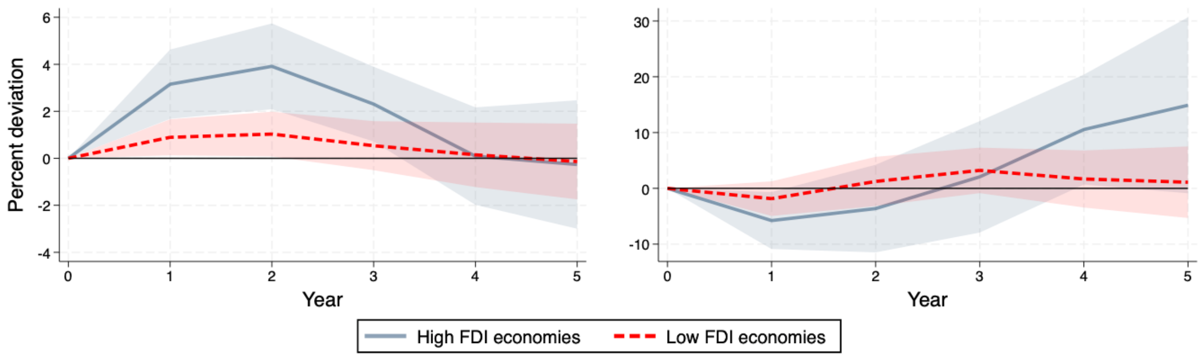
Note: Local projections of advanced and emerging economies are estimated on a sample of 31 and 147 countries respectively, over a 1988 - 2018 year range, using equation (2) with 90 percent confidence bands. Other energy types were statistically insignificant.

Figure A3: Renewable adoption for upper 75% and lower 25% of economies in FDI



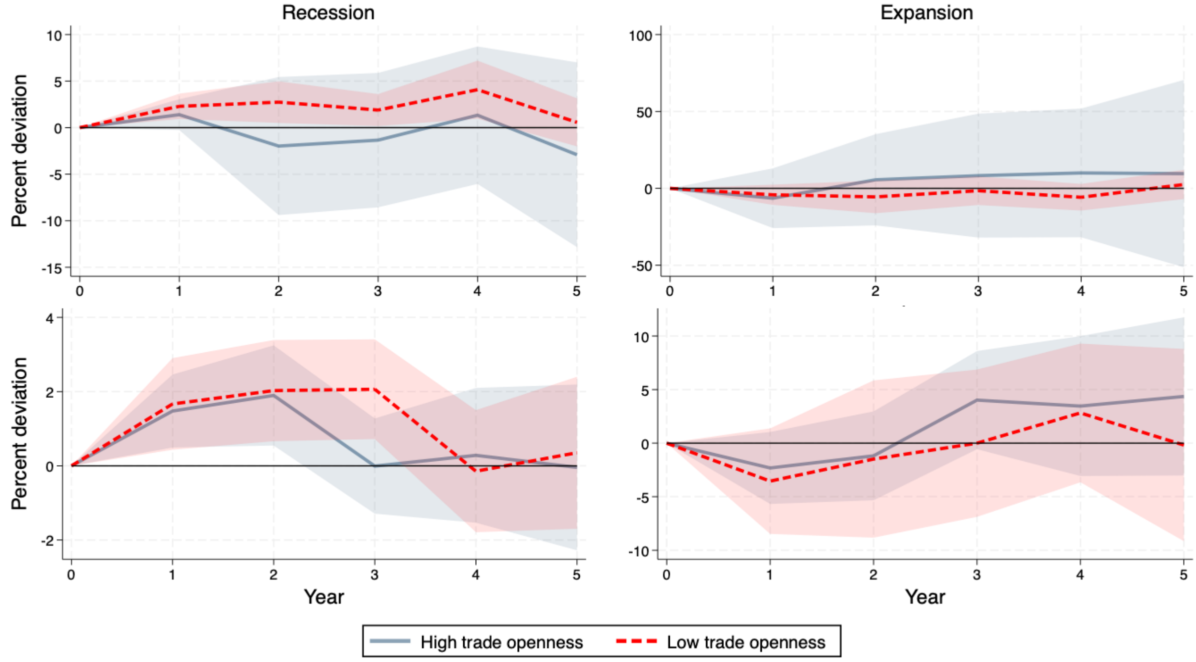
Note: Local projections of high FDI and low FDI economies are estimated on a sample of 43 and 42 countries respectively, over a 1988 - 2018 year range, using equation (2) with 90 percent confidence bands.

Figure A4: Renewable adoption of advanced and emerging economies with high FDI and low FDI



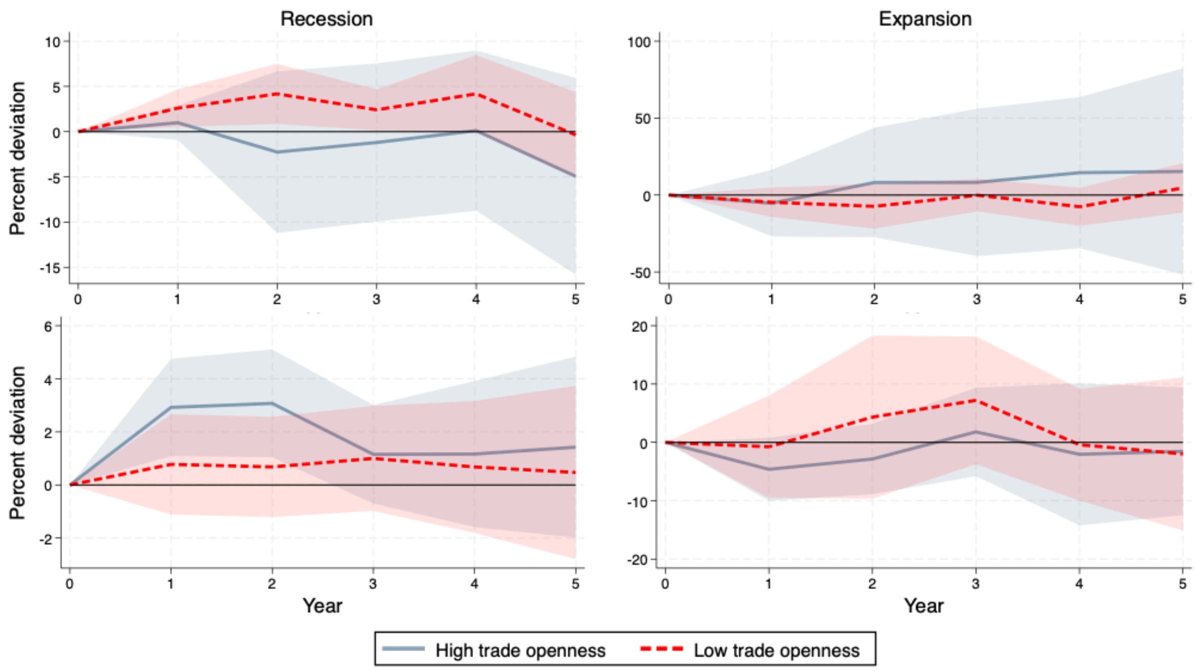
Note: top chart local projections of advanced economies with high FDI and low FDI are estimated on a sample of 8 and 23 countries respectively. Bottom chart local projections of emerging economies on a sample of 47 with high and 99 with low FDI, over a 1988 - 2018 year range, using equation (2) with 90 percent confidence bands.

Figure A5: Renewable adoption in advanced and emerging economies with high trade openness and low trade openness



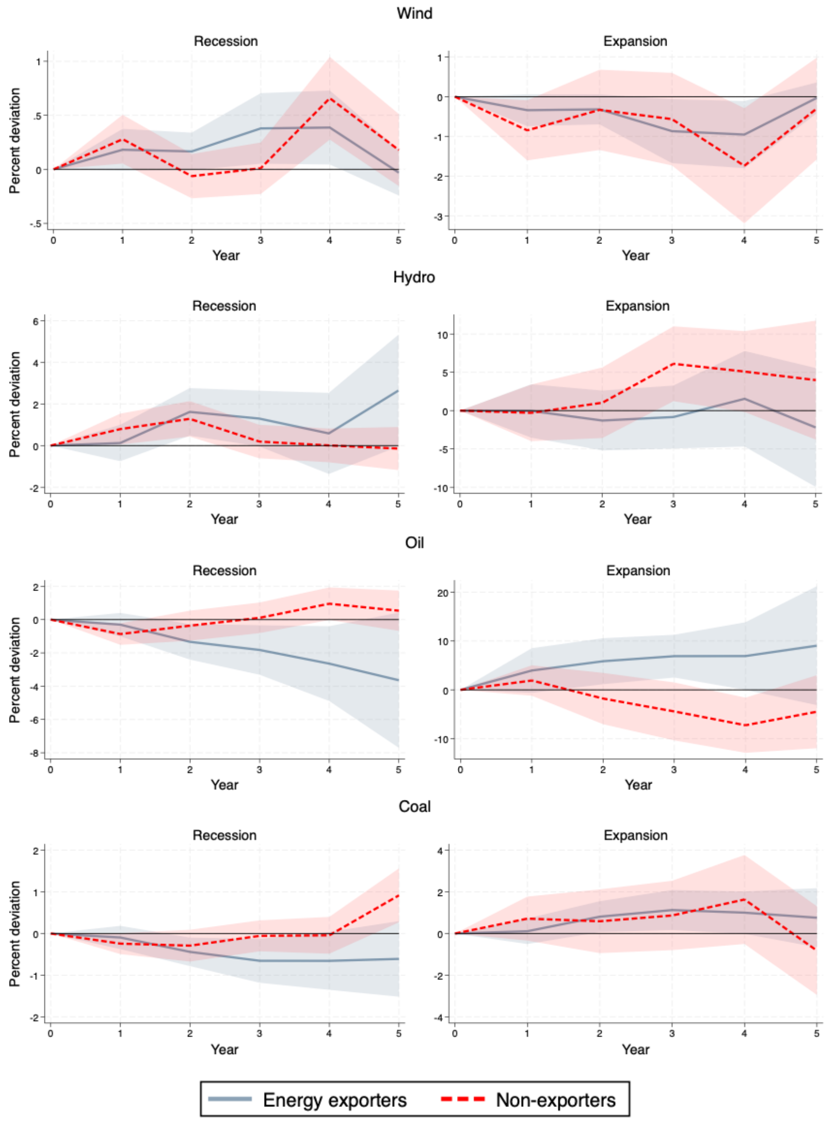
Note: top chart local projections of advanced economies with high trade openness and low trade openness are estimated on a sample of 13 and 18 countries respectively. Bottom chart local projections of emerging economies on a sample of 65 with high and 70 with low trade openness, over a 1988 - 2018 year range, using equation (2) with 90 percent confidence bands.

Figure A6: Renewable adoption for advanced and emerging economies in upper 75% and lower 25% in trade openness



Note: top chart local projections of advanced economies with high trade openness and low trade openness are estimated on a sample of 11 and 7 countries respectively. Bottom chart local projections of emerging economies on a sample of 28 with high and 37 with low trade openness, over a 1988 - 2018 year range, using equation (2) with 90 percent confidence bands.

Figure A7: Energy mix during business cycles of energy-exporters



Note: Local projections of energy exporters are estimated on a sample of 35 countries, over a 1988 - 2018 year range, using equation (2) with 90 percent confidence bands. Other energy types were statistically insignificant.