

# Time-Frequency Spillovers and the Determinants among Fossil Energy, Clean Energy and Metal Markets

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Growing awareness of global warming because of the overuse of fossil fuels is accelerating the shift from fossil energy to clean energy worldwide. However, clean energy technologies are strongly dependent on the availability of metals, and the production and smelting of metals requires the use of fossil fuels. Studies of this enhanced energy-metal relationship are needed to promote a low-carbon energy transition.

In contrast to most spillover studies based on a time-domain approach, we use Baruník and Křehlík's time-frequency spillover framework to provide insight into how the connectedness among fossil energy, clean energy and metal markets differs in the short and long term from a green finance perspective in the context of the current energy transition. Using a complex network approach, the strength and direction of connectedness in different time horizons are investigated. Specifically, we empirically explore the impact of economic fundamentals, financial factors and external uncertainties on the time-frequency connectedness among fossil energy, clean energy and metal markets.

We find strong connectedness among the fossil energy, clean energy and metals markets. In addition, aggregate spillovers increase significantly during periods of financial and economic uncertainty. Rare earth metals are vulnerable to fluctuations in global clean energy markets, particularly in wind energy market, which may be related to the fact that rare earth metals are a critical raw material for wind energy equipment. While base metal market is vulnerable to shocks from the energy markets in the short term, it can have a long-term impact on the rare earth metals and clean energy sub-markets. Fossil energy market is shocked by clean energy market in the short term, but can be a strong spillover transmitter in the long term. Solar market is a net spillover contributor in any frequency domain, but wind market can shift from being a short-term spillover transmitter to a long-term spillover receiver. Interestingly, we find that the total connectedness among fossil energy, clean energy and metal markets is driven by economic policy uncertainty in the short term, while stock market uncertainty and economic fundamentals become the main drivers in the long term, with the conclusions remaining robust to different spillover measures.

Environmentally friendly investors can use our findings to build better portfolio diversification and hedging strategies at different time horizons, while policymakers can distinguish between short- and long-term policy-making decisions to avoid cross-contagion between the energy and metal markets and effectively promote clean energy investments.

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