The Impact of Green Financial and Monetary Policy on the Low-Carbon Energy Transition: Global Empirical Evidence

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Abstract

Aligning economic pathways with a 2°C climate target implies rapid decarbonisation and a substantial increase in renewable energy (RE) investment and deployment. The financial system plays a key role in mobilising these investments, thereby enabling an orderly transition. To support these efforts and address related climate risks, financial regulators and central banks increasingly adopted green financial and monetary policies (GFMP). However, empirical evidence on the effectiveness of GFMP in promoting a smooth transition remains scarce. This paper sheds light on the impacts of GFMP on RE capacity additions, a key transition indicator. I construct a country-level GFMP index capturing the flow and stock of policy intensity and mix across 26 countries for the years 2000 to 2023. Leveraging this index, I deploy two-way fixed effects and quantile panel regressions to quantify aggregate and policy type-specific impacts, and estimate heterogeneous conditional effects across the distribution. Results show a positive relationship between GFMP intensity and RE capacity additions. On average, each adopted GFMP is associated with an addition of 1.12 gigawatt RE capacity over the long-term, corresponding to 2 Mt CO_2 emissions avoided annually when displacing fossil energy sources. Distinguishing by policy type, I find positive effects for incentive-based instruments such as credit allocation rules, but not for informational instruments such as climate stress testing. The size of effect shows high heterogeneity, suggesting that countries with relatively more mature RE markets experience larger benefits from adopting GFMP. This study provides an early empirical quantification of the impact of GFMP on the low-carbon energy transition, and presents a GFMP index that can be deployed in future research. Findings hold important policy implications on the green transition.

1 Introduction

Climate change, famously described as the "greatest market failure the world has ever seen" (Stern, 2007) poses substantial risks to social and economic systems. To mitigate the most severe impacts of climate change, the global economy must drastically decarbonize. The IPCC highlighted that the window of opportunity for such an orderly transition is closing rapidly (IPCC, 2022). As the largest source of global CO_2 emissions, this applies particularly to the power sector, with Paris-aligned economic pathways implying a substantial increase in renewable energy (RE) deployment (Luderer et al., 2018). However, there is an investment gap of USD 400 billion per year to meet the COP28 pledge of tripling installed RE capacity by 2030 (IEA, 2024). The financial system plays a key role in closing this finance gap by (re-)allocating funds and pricing related climate risks, thereby enabling a smooth low-carbon transition. For example, because many low-carbon energy technologies are more capital-intensive than traditional high-carbon solutions, the cost and availability of capital set in financial markets is a key determinant of investment, energy mix and the rate of decarbonisation (Egli et al., 2018; Hirth and Steckel, 2016). The increasing awareness for these implications and climate change's wider economic impacts, for example for inflation and financial stability, have led to the launch of private and public initiatives (e.g., GFANZ, NGFS) and intensified discussion on the role of regulators and central banks in "greening" financial flows (Campiglio et al., 2018; Dikau and Volz, 2021). Against this context, a growing number of financial regulators and monetary authorities, including the United Kingdom's Financial Conduct Authority and the European Central Bank, have added green financial and monetary policies (GFMP) to their toolkits (NGFS, 2024). These are measures that (in)directly target the structure and conditions of the financial system to address climate-related concerns. To date, mostly two kinds of policies have been adopted. First, informational instruments such as disclosure requirements and climate stress testing, which aim to increase climate-related information (e.g., climate risk exposure, vulnerability, and management) available to financial actors. Second, incentive-based instruments such as capital requirements or asset eligibility rules that change the financial incentive structure by altering the relative prices to which market participants are exposed. These incentive-based policies present a more direct intervention, designed to steer capital towards low-carbon investments that promote an orderly transition (Baer et al., 2021).

While a variety of GFMP instruments have been adopted, empirical evidence on the effectiveness of these instruments in fostering a smooth transition remains scarce. The motivation of this paper is to shed light on the economic impacts of GFMP by empirically assessing the relationship between countries' GFMP and low-carbon transition performance. More specifically, I investigate whether GFMP intensity can explain renewable energy (RE) capacity additions. This is of special interest, because power sector dercarbonisation via RE deployment is a top priority on the global political agenda, and a key indicator of countries' transition towards a low-carbon energy and economic system.

I collect data on GFMP adoption across 26 countries for the years 2000 to 2023, and group adopted instruments into six distinctive policy types. I create a country-level GFMP index that captures the flow and stock of policy intensity and mix over time. Methodologically, I follow a two-way fixed effects panel regression approach, investigating the relationship between GFMP and RE capacity additions across countries over time. I distinguish between short-term and long-term effects, and between policy types to estimate instrument-specific impacts. As an alternative model, I apply quantile panel regression techniques to obtain coefficients at different points of the dependent variable's distribution. This approach provides additional analytical depth and robustness by considering asymmetric effects from heterogeneity and capturing nonlinear relationships without requiring a strict functional form (Machado and Silva, 2019).

Results are threefold. First, I find a significant positive relationship between the long-term stock of GFMP and RE capacity additions. On average, each adopted GFMP is associated with an addition of 1.12 gigawatt RE capacity over the long-term. This corresponds to 2 Mt CO_2 emissions avoided annually when displacing fossil energy sources, equivalent to the abatement of CO_2 emissions of 266,000 G20 citizens. Second, disentangling the aggregate impact, I find positive effects for incentive-based policies (credit allocation, green bonds, prudential climate risk management), but not for informational instruments (climate stress testing, green finance guidelines, disclosure requirements). These findings suggest that while adopted GFMP can accelerate the low-carbon transition and serve as a complementary pillar to conventional climate policy, policymakers wishing to promote transition efforts may want to re-think current policy mixes. Third, quantile analysis reveals a high degree of heterogeneity of effects, with the impact at the 90th percentile being 2.7 times larger than at the 10th percentile. This implies that countries with relatively more mature RE markets experience stronger benefits from adopting GFMP than countries at an early stage of the RE technology pathway.

This study contributes to the literature in three respects. First, it provides an early empirical assessment of GFMP's real-economy impacts and sheds light on the heterogeneity of outcomes, providing a deeper understanding of the effectiveness of GFMP beyond theoretical models. Second, I present a comprehensive GFMP index, which can be utilised in future studies investigating other relevant transition outcome variables that are beyond the scope of this paper. Third, the coverage of major economies, representing 75% of global emissions and 82% of world GDP, offers a comparative perspective and high policy relevance.

The remainder of the paper is structured as follows. Section two lays out the theoretical background. Section three describes the data. Section four outlines the research design. Section five presents results. Section six concludes.

2 Background

2.1 Context and literature

GFMPs are tools deployed by financial authorities and central banks to address climate-related concerns in the financial sector. First, GFMP can help tackle physical and transition climate risks. Physical risks arising from acute or chronic impacts of changes in the climate system can result in significant damages and impairment of financial assets' underlying economic activities (Burke et al., 2015; Dietz et al., 2016; Kotz et al., 2024). Transition risks stemming from changes in climate policies, the cost and availability of technologies, or demand and supply patterns, can lead to sudden adjustments in asset prices and financial instability (Battiston et al., 2017; Bolton et al., 2020; Roncoroni et al., 2021). GFMP instruments like climate stress testing and disclosure requirements support policymakers and financial market participants to identify, quantify, manage, and price such risks. For example, investors are increasingly demanding a "carbon risk premium" as compensation for their exposure to high-emission firms (Bolton and Kacperczyk, 2021). Second, GFMP can support making "finance flows consistent with a pathway towards low greenhouse gas emissions", as noted in Article 2 of the Paris Agreement (UN, 2015). For instance, capital allocation rules can incentivise redirecting investments into activities supporting the low-carbon transition. Consequently, regulators and central banks have increasingly implemented GFMP to respond to climate risks and meet wider sustainability objectives. Recent examples include the carbon emission reduction facility introduced by the People's Bank of China in 2021, the climate stress test conducted by the European Central Bank in 2022, and climate risk disclosure requirements established by Japan's Financial Services Agency in 2023.

In line with these developments, a growing body of academic research is devoted to GFMP, broadly focused on three key themes. First, numerous conceptual frameworks and theoretical models study different GFMP instruments and approaches of how and under which conditions financial supervisors can align their policies to the realities of climate change. Conducting a systemic literature review, Hidalgo-Oñate et al. (2023) find that research on GFMP approaches has focused on disclosure requirements, climate stress testing, differentiated capital requirements, and green finance frameworks. Baer et al. (2021) identify a promotional gap in European GFMP, concluding that regulators primarily focus on prudential objectives via informational instruments rather than actively steering the transition through incentive-based instruments. In a similar vein, Chenet et al. (2021) argue that this primarily informational approach pursued to date is limited in addressing climate-related financial challenges, because of the inherent radical uncertainty around climate impacts which makes 'efficient' price discovery difficult. In line with their prominence in the regulatory arena, climate stress testing frameworks, which estimate the financial impact of a climate scenario versus a business-as-usual baseline, have been deployed and assessed by multiple authors (Reinders et al., 2023; Pang and Shrimali, 2024; Gasparini et al., 2023). Furthermore, a variety of incentive-based instruments has been simulated in macro-financial models, suggesting that, despite temporary financial stability trade-offs, climate-augmented financial and monetary policies can reduce bank portfolio emissions and inflation volatility, while supporting green investments and overall welfare (Dafermos and Nikolaidi, 2021; Dunz et al., 2021; Monasterolo and Raberto, 2017; Schoenmaker, 2021). Establishing a set of GFMP can induce a virtuous cycle of emission reductions, long-term stable financial sector and economic growth (Lamperti et al., 2021).

Second, it is increasingly researched which institutional, economic and political characteristics contribute to the adoption and diffusion of GFMP. Among the relevant factors identified are, for example, the central bank governance framework and independence, the economy's carbon intensity, and the country's vulnerability and exposure to climate change (D'Orazio, 2022b; D'Orazio and Popoyan, 2023; Feldkircher and Teliha, 2024; Gupta et al., 2023).

Third, an evolving but under-researched theme is the empirical assessment of GFMP. Early attempts to shed light on GFMP's empirical effects were made by D'Orazio and Dirks (2022) who identify a negative relationship between climate-related financial policies and carbon emissions in G20 countries, and Miguel et al. (2024) who investigate the impact of climate-related capital requirements on bank lending and find that while regulated banks reduce brown lending, the net effect on real economic activity and emissions is neutral due to substitution effects. Conducting a comparative analysis of green financial policies in OECD countries, Steffen (2021) detects a positive link between low-carbon financial policy intensity and GDP per capita. Using machine learning methods, D'Orazio and Pham (2025) examine climate-related financial policy sequencing patterns, and identify the relative importance of these policies and other economic characteristics in predicting decarbonisation outcomes, highlighting the importance of tailoring GFMP to specific country contexts. While the contributions to date have progressed our understanding of the drivers and (theoretical) outcomes of GFMP, empirical studies remain surprisingly scarce. This is partly because existing empirical research typically examines policies directly targeting polluting sectors but less so policies directed at the financial sector intended to indirectly address climate transition objectives. As highlighted by the NGFS (2024), and considering the substantial public and private resources involved in policy development and compliance, it is crucial to examine the impacts of GFMP on the low-carbon energy transition in more depth.

Conceptually, GFMP are transmitted through financial intermediaries in the credit and banking system to the real economy via three key channels: the price or interest rate channel, the lending quantity channel, and the portfolio re-balancing channel (Monasterolo et al., 2024). By way of these transmission channels, GFMP lead to increased liquidity for companies willing to invest in low-carbon activities, de-risking of green investments, and thus relatively higher green capital productivity. This translates into increased green investment demand, a reduction in the low-carbon infrastructure and energy investment gap, and changes in the sector and technology composition of the economy. Ultimately, these financial adjustments affect macroeconomic performance, including consumption, GDP, sovereign debt, and the energy mix. More specifically, the link between financial sector conditions and low-carbon energy deployment is rooted in the fact that the cost of capital (CoC) for energy investments is a key determinant for the competitiveness of RE technologies, which are relatively more capital intensive vis-a-vis fossil fuel alternatives. Indeed, energy modeling has shown how the CoC drives overall energy system cost, technology mix and the rate of energy system decarbonisation (Polzin et al., 2021). For example, Egli et al. (2018) estimate that 40% of the decline in electricity generation cost in the early RE industry is stemming from more favourable financing conditions (lower CoC). Hirth and Steckel (2016) demonstrate that the share of RE in the cost-optimal energy mix comprises 40% under a CoC of 3%, but is almost zero at a CoC of 15%. Schmidt et al. (2019) show how interest rate dynamics, for example induced by financial and monetary policies, can change the CoC of low-carbon technologies and thereby promote or jeopardize RE deployment. In a similar vein, analysing the relationship between financial capital and energy transitions, Best (2017) concludes that policies that affect the structure and conditions of the financial system can facilitate the use of relatively more capital-intensive RE technologies compared to incumbent fossil-fuel energy generation types. To sum up, financial conditions (i.e., CoC), which are affected by GFMP, are a major determinant of energy investment and mix. Therefore, there is a strong logical chain between GFMP and RE deployment, transmitted through macro-financial channels. Figure 1 shows these stylised transmission channels.

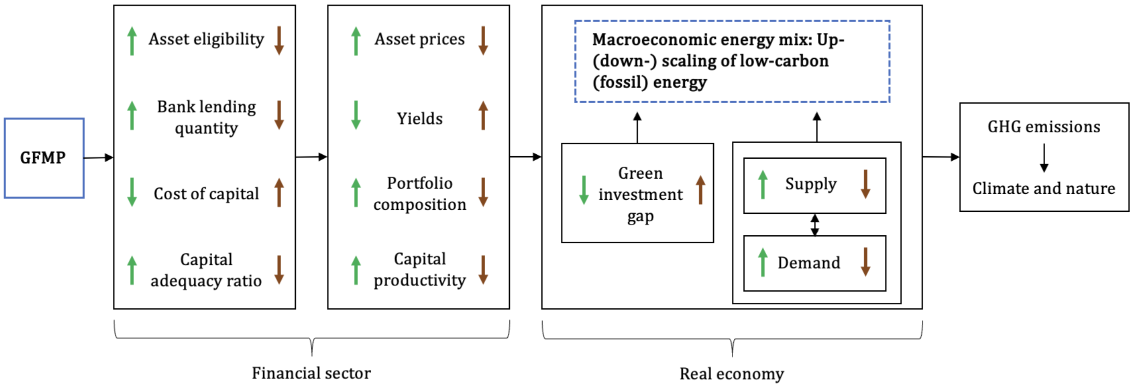

Figure 1: Macro-financial transmission channels of GFMP

Note: Based on Monasterolo et al. (2024). Upward- (downward) facing arrows indicate positive (negative) trend. Green (brown) arrows indicate potential effects on low- (high-) carbon economic activities.

2.2 Hypotheses

Based on the conceptual framework, the stock of GFMP codifies a country's policy ambition regarding the greening of the financial system and sustainable transformation of the economy. This implies that higher policy intensity, as measured by the number of adopted GFMP, can be expected to enable a more rapid transition. That is, when GFMP effectively induce financial institutions to reduce their high-carbon asset exposure and provide more favourable conditions for low-carbon investments, one would expect a more pronounced up-scaling of low-carbon energy technologies for countries with a larger stock of GFMP. This scaling-up takes the form of RE capacity additions, a proxy of renewable energy investment and key indicator of transition performance. From these conceptual macro-financial mechanisms, the following hypotheses arise.

Hypothesis 1: There is a positive relationship between a country's stock of GFMP and renewable energy capacity additions.

Hypothesis 2: Incentive-based GFMP instruments have a more positive relationship with renewable energy capacity additions than informational instruments.

3 Data

3.1 GFMP data

I collect data on GFMP adoption from datasets on climate-related financial policies provided in D'Orazio (2021, 2022a), the Green Monetary and Financial Policies Tracker by the E-axes Forum on Climate Change, Macroeconomics and Finance, and manual research of official documents. Manuel research involves review of climate-related publications by financial regulators and central banks from 2020 to 2023 to increase time coverage. This data collection process yields GFMP observation across 26 countries for the years 2000 to 2023. I group observations into six distinctive policy types: Credit allocation, green bond rules, green finance guidelines, climate stress testing, other prudential climate risk management, and other disclosure requirements (non-financial institutions). Next, I create a country-level GFMP index (c, t) which is increased by 1 in year t when country c adopts a GFMP, thus capturing the flow and stock of policy intensity and mix over time.

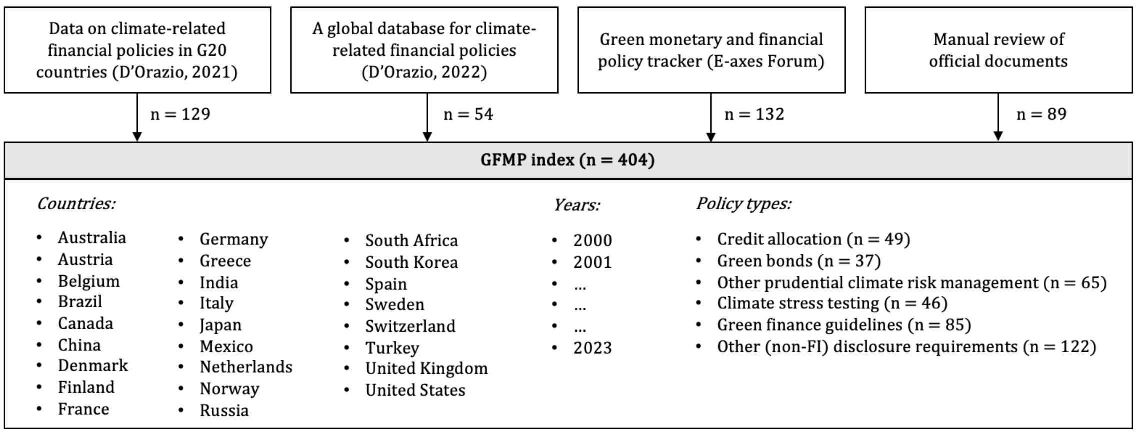

Figure 2: Data for GFMP index construction

The GFMP index presents a heterogeneous picture of countries' policy ambition. While leaders such as France and Germany adopted 32 and 25 polices, laggards such as Turkey and South Africa implemented 5 and 6 policies (Figure 3). Policy mixes differ by country, with some relying mostly on conventional informational measures (e.g., disclosure requirements), and others integrating more incentive-based instruments (e.g., credit allocation) in their GFMP mixes. European Union countries not only tend to have implemented a larger number of GFMP relative to other regions, but also show more homogeneity in policy mix, even though at different intensities (Figure 4). This is partially driven by common EU-wide strategies executed by the European Banking Authority (EBA) and the European Central Bank (ECB). Disentangling the stock of adopted GFMP into distinctive policy types, it becomes apparent that disclosure requirements and green finance guidelines dominate, but climate stress testing and credit allocation have seen an uptake in recent years, especially after the launch of the NGFS in 2017 (Figure 5).

Figures 3 to 5 show that most countries - albeit to different levels - have started to develop a versatile GFMP toolbox. Notable, the data reveals continuous progression

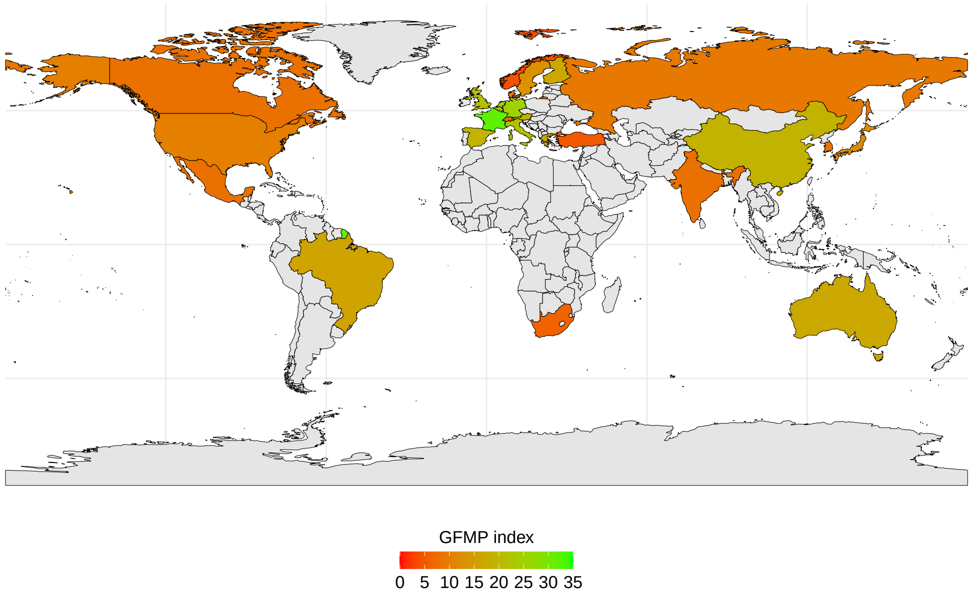

Figure 3: GFMP heatmap (2022)

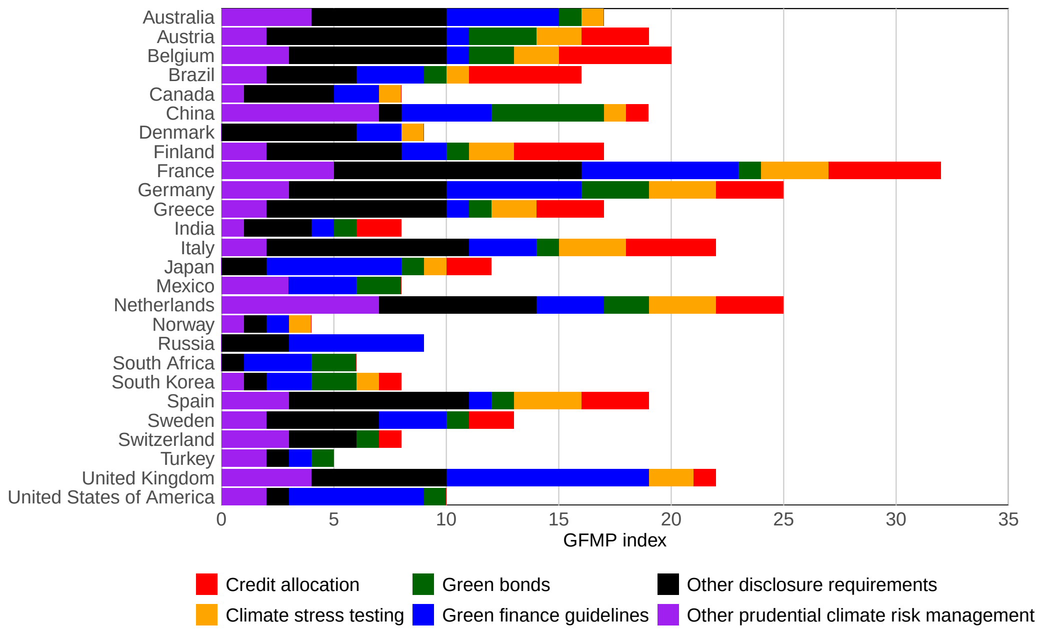

Figure 4: Cumulated number of GFMP (2022)

in policy uptake over time, indicating ongoing policy innovation in many countries. This is in line with the development that, firstly, countries increasingly acknowledge the threat of climate-related risks to the financial system and stability, and thus policymakers and central bankers are exploring options to embed climate concerns into prevailing regulatory regimes (Carney, 2015; NGFS, 2019; Elderson, 2024). And secondly, the role of the financial system in enabling the green transformation by scaling-up climate finance has gained considerable importance over the last two decades (Bolton et al., 2024; Carney, 2021).

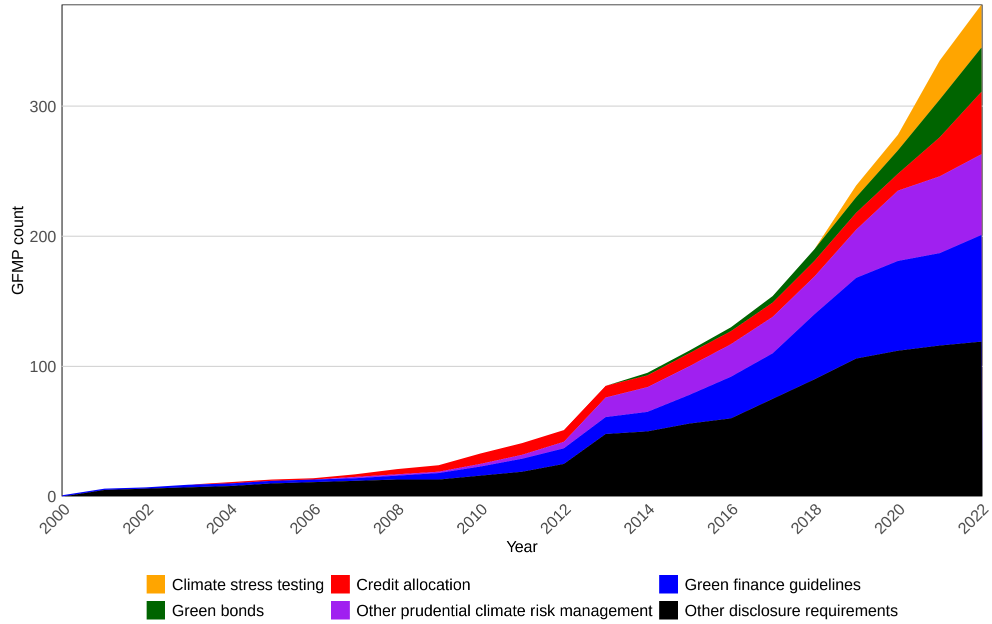

Figure 5: GFMP adoption by policy type

3.2 Other data

Data on RE capacity, capturing wind and solar sources, by country and year is collected from the International Renewable Energy Agency (IRENA). I calculate RE capacity additions as the difference in RE capacity between year t and year t-1. A set of economic and financial control variables is collected from public sources. More specifically, GHG emissions, carbon prices, population, GDP, share of domestic credit provision, and regulatory quality is obtained from The World Bank Group. Data on inflation and financial development is gathered from the International Monetary Fund (IMF). Table 1 summarizes deployed data and corresponding sources. Table 2 presents aggregate descriptive statistics of key variables.

Table 1: Overview of data and sources

Data	**Source**
GFMP	D'Orazio (2021, 2022a) E-axes Forum policy tracker Review of regulators' publications
Renewable energy capacity	International Renewable Energy Agency
GHG emissions Carbon prices Population GDP Domestic credit provision Regulatory quality	The World Bank Group
Inflation (CPI) Financial development	International Monetary Fund

Table 2: Key descriptive statistics

Statistic	N	Mean	St. Dev.	Median	Min	Max
RE capacity (GW)	598	19.0	59.1	3.5	0.0	759.0
RE capacity additions (GW)	598	3.0	10.3	0.5	−0.1	123.0
Emissions intensity (MtCO2/billion USD GDP)	598	0.2	0.1	0.2	0.05	0.7
Carbon price (USD/tCO2e)	598	10.5	19.4	0.0	0.0	129.8
Population (mln.)	598	158.5	337.8	50.7	4.5	1,417.2
GDP per capita (USD)	598	44,995.8	20,164.1	49,936.7	3,094.5	91,068.6
Inflation (perc.)	598	3.5	5.5	2.3	−1.7	72.3
Domestic credit provision (perc.)	598	104.9	45.3	105.8	12.2	221.1
Regulatory quality	598	1.0	0.7	1.3	−1.1	2.0
Financial development	598	0.7	0.2	0.7	0.3	1.0

4 Methodology

The core model follows a two-way fixed effects panel regression approach, investigating the relationship between GFMP and RE capacity additions across countries over time. RE capacity additions as the outcome variable of interest is motivated by the following facts. As the largest contributor to global CO_2 emissions, the energy sector and its decarbonisation through increased RE technology deployment is a key policy priority in many countries. As such, economic pathways in line with the Paris Agreement's 1.5–2°C target always imply a substantial increase in RE capacity (Luderer et al., 2018), highlighting the need to better understand which policies, including GFMP, can contribute to an acceleration in RE uptake. Adding to this, there is an investment gap of USD 400 billion per year between 2024 and 2030 to meet the COP28 pledge of tripling installed RE capacity by 2030 (IEA, 2024). With the financial sector playing a key role in mobilising private (and public) capital to fund these investments, it is of natural interest to investigate the role of GFMP in scaling up RE capacity. In doing so, I consider the aggregate impact, and distinguish between the short-term and long-term effects of GFMP, and between policy types to estimate instrument-specific impacts. As an alternative model, I conduct quantile panel regression analysis to explore asymmetric effects across the distribution.

4.1 Two-way fixed effects model (TWFE)

When a GFMP is adopted, it will start to affect financial dynamics and thus economic and energy outcomes. Some policies may kick in immediately, others materialize more gradually or with a delay. So, RE capacity (additions) in year t is, among other things, a function of the overall stock of GFMP implemented in the years (t-1), (t-2), (t-3) and so on. The main specification (Equation 1) explores this aggregate effect of GFMP on RE capacity additions, with GFMP_{it} being the total stock of GFMP in country i and year t. Y_{it} is the dependent variable: RE capacity additions.

$$Y_{it} = \alpha_i + \gamma_t + \beta_1 \text{GFMP}_{it} + \beta_2 \sum X_{it} + \epsilon_{it} \tag{1}$$

To factor in potential lags between the time of adoption and effects induced by the policies, I break the overall impact down into short- and long-term effects by aggregating policies in two different metrics: the stock of short-term policies and the stock of long-term policies.[1] In Equation 2, STGFMP_{it} refers to the short-term stock of GFMP, capturing policies adopted in the years t, t-1, and t-2, and LTGFMP_{it} refers to the long-term stock of GFMP, capturing policies adopted in the years t-3, t-4, ..., t-23. As a robustness test, the definition of the short- and long-term stock is varied by moving the threshold from 3 to 4 and 5 years, respectively. This is in line with Gumber et al. (2024), who analyse more than 12,000 RE project timelines across 48 countries and find an average commissioning time of about 3 years, with some RE technologies such as offshore wind taking just over 5 years.

$$Y_{it} = \alpha_i + \gamma_t + \beta_1 \text{STGFMP}_{it} + \beta_2 \text{LTGFMP}_{it} + \beta_3 \sum X_{it} + \epsilon_{it} \tag{2}$$

Taking on an even more granular perspective, Equation 3 differentiates between six distinctive policy types, with CA_{it} representing credit allocation, GB_{it} green bonds, OPCRM_{it} other prudential climate risk management, CST_{it} climate stress testing, GFG_{it} green finance guidelines, and ODR_{it} other disclosure requirements. Coefficients β_1 to β_6 capture the effect of the stock of individual policy instruments on RE capacity additions.

$$\begin{aligned} Y_{it} = \alpha_i + \gamma_t + \beta_1 \text{CA}_{it} + \beta_2 \text{GB}_{it} + \beta_3 \text{OPCRM}_{it} \\ + \beta_4 \text{CST}_{it} + \beta_5 \text{GFG}_{it} + \beta_6 \text{ODR}_{it} + \beta_7 \sum X_{it} + \epsilon_{it} \end{aligned} \tag{3}$$

Across all models, α_i is added as country fixed effects to control for time-invariant factors such as different socio-economic characteristics, political environments and renewable energy potentials. In turn, γ_t captures unobserved time fixed effects, controlling for inter-temporal trends that are homogeneous across countries, such as the global decline in low-carbon technology costs. X_{it} is a set of control variables to account for other relevant economic, financial and governance features. These include GDP per capita, population, emissions intensity, carbon prices, inflation, regulatory quality, financial development, and domestic credit provision. Lastly, ϵ_{it} is the error term.

4.2 Quantile regression model

As an alternative model, I deploy a quantile panel regression with country and time fixed effects to obtain coefficients at different quantiles of the dependent variable (Equation 4). This econometric technique follows the Method of Moments Quantile Regression (MMQR) approach introduced by Machado and Silva (2019).

$$Q_{Y_{it}}(\tau_k | \alpha_i \chi_{it}) = (\alpha_i + \delta_i q(\tau)) + \beta_1^{\tau} \text{GFMP}_{it} + \beta_2^{\tau} \sum X_{it} + Z'_{it} \gamma_q(\tau) \tag{4}$$

where $Q_{Y_{it}}(\tau_k | \alpha_i \chi_{it})$ is the quantile distribution of the dependent variable, $(\alpha_i + \delta_i q(\tau))$ the scalar coefficient indicating quantile-τ fixed effect for country i, $GFMP_{it}$ the GFMP stock for country i in year t, and X_{it} a set of controls including GDP per capita, population, emissions intensity, carbon prices, inflation, regulatory quality, financial development, and domestic credit provision. I use bootstrapped, and in a

[1] Eskander and Fankhauser (2020) and D'Orazio and Dirks (2022) follow a similar approach.

robustness test Kernel-based, standard errors as they do not impose strong parametric assumptions and account for heteroskedasticity and autocorrelation. The quantile regression model quantifies conditional heterogeneous effects of the factors driving RE capacity additions by separately estimating relationships at different quantiles of the dependent variable. As such, it is more robust to outliers, sheds light on asymmetric policy responses across lower, median, or upper portions of the distribution, and captures potentially nonlinear relationships across quantiles without requiring a strict functional form (Machado and Silva, 2019).

5 Preliminary results

5.1 TWFE results

Results of the main TWFE model are threefold. First, I find a significant positive relationship between countries' overall stock of GFMP and RE capacity additions (Table 3). In the main specification (Column 1), on average, each adopted GFMP is associated with an addition of 0.53 gigawatt RE capacity. This corresponds to 0.96 Mt CO_2 emissions avoided annually when displacing fossil energy sources, equivalent to taking about 210,000 passenger vehicles off the street.

Table 3: Aggregate results

	Dependent variable: RE capacity additions			
	(1)	(2)	(3)	(4)
GFMP stock	0.534***	0.595***	0.755***	−0.045
	(0.100)	(0.070)	(0.116)	(0.076)
GDP per capita	0.0003**	0.0001**	0.0001**	−0.0004***
	(0.0001)	(0.00004)	(0.00004)	(0.0001)
Population	0.097***	0.015***	0.014***	0.081***
	(0.010)	(0.001)	(0.001)	(0.011)
Emissions intensity	−146.691***	−0.707	−1.457	−122.942***
	(9.539)	(3.260)	(3.377)	(10.463)
Carbon price	−0.012	−0.037*	−0.028	−0.017
	(0.019)	(0.020)	(0.023)	(0.019)
Inflation	−0.007	0.081	0.079	0.117*
	(0.058)	(0.070)	(0.074)	(0.062)
Regulatory quality	1.325	−2.318**	−2.759***	5.239***
	(1.577)	(0.934)	(0.985)	(1.747)
Financial development	22.360***	−3.036	−4.049	8.595
	(5.615)	(3.389)	(3.538)	(5.949)
Domestic credit provision	0.077***	0.074***	0.080***	0.032*
	(0.017)	(0.011)	(0.012)	(0.018)
Constant		−7.831***		
		(2.211)		
FE (time)	Yes	No	Yes	No
FE (country)	Yes	No	No	Yes
Observations	598	598	598	598
R^2	0.558	0.424	0.386	0.472
Adjusted R^2	0.512	0.416	0.352	0.440
Residual Std. Error		7.850 (df = 588)		
F Statistic	75.903*** (df = 9; 541)	48.177*** (df = 9; 588)	39.530*** (df = 9; 566)	55.957*** (df = 9; 563)

Note: Averages with standard errors in parentheses. Main specification in Column 1, specifications with no or partial fixed effects in Columns 2 to 4. Significance levels: *p<0.1; **p<0.05; ***p<0.01

Table 4: Short- and long-term results

	Dependent variable: RE capacity additions		
	Main	Robustness A	Robustness B
	(1)	(2)	(3)
GFMP ST(3)	−0.238		
	(0.175)		
GFMP LT(3)	1.116***		
	(0.147)		
GFMP ST(4)		−0.217	
		(0.148)	
GFMP LT(4)		1.494***	
		(0.173)	
GFMP ST(5)			−0.031
			(0.130)
GFMP LT(5)			1.608***
			(0.191)
GDP per capita	0.0002**	0.0002**	0.0003**
	(0.0001)	(0.0001)	(0.0001)
Population	0.093***	0.092***	0.093***
	(0.010)	(0.010)	(0.010)
Emissions intensity	−145.759***	−145.426***	−144.600***
	(9.310)	(9.180)	(9.200)
Carbon price	−0.006	−0.004	−0.007
	(0.019)	(0.019)	(0.019)
Inflation	0.010	0.010	0.018
	(0.057)	(0.056)	(0.056)
Regulatory quality	1.883	2.367	2.011
	(1.543)	(1.526)	(1.524)
Financial development	19.086***	17.614***	18.851***
	(5.516)	(5.451)	(5.440)
Domestic credit provision	0.068***	0.066***	0.066***
	(0.016)	(0.016)	(0.016)
Observations	598	598	598
R^2	0.580	0.592	0.590
Adjusted R^2	0.536	0.549	0.547
F Statistic (df = 10; 540)	74.608***	78.290***	77.819***

Note: Averages with standard errors in parentheses. In Column 1, the short-term stock of GFMP is defined as policies adopted in the previous 3 years (t, t-1, t-2), and the long-term GFMP stock as policies adopted in all years prior to the previous 3 years (t-3, ..., t-23). In Columns 2 and 3, the threshold is changed to 4 and 5 years, respectively. Significance levels: *p<0.1; **p<0.05; ***p<0.01

Second, when distinguishing between the short-term and long-term effect, on average, each GFMP is associated with an addition of 1.12 gigawatt RE capacity over the long-term (Table 4). This corresponds to 2 Mt CO_2 emissions avoided annually when displacing fossil energy sources, equivalent to abatement of CO_2 emissions of 266,000 G20 citizens. I find no effect for the short-term. The larger effect when considering the long-term policy stock relative to the overall stock including recent short-term policies suggests that in order to translate into RE impacts, GFMP require multiple time periods to be transmitted to the real economy. This is as expected considering that the financial and economic adjustments underlying the scaling up of RE capacity may not be immediately responsive.

Third, disentangling the impact by GFMP type (Table 5), I find positive effects

Table 5: Policy type-specific results

	Dependent variable: *RE capacity additions*
Credit allocation	0.807** (0.372)
Green bonds	7.255*** (0.857)
Other prudential climate risk management	5.924*** (0.318)
Climate stress testing	−1.157 (1.956)
Green finance guidelines	−0.069 (0.280)
Other disclosure requirements	−1.030*** (0.212)
GDP per capita	−0.0001 (0.0001)
Population	0.068*** (0.008)
Emissions intensity	−85.416*** (8.510)
Carbon price	−0.003 (0.016)
Inflation	−0.062 (0.044)
Regulatory quality	4.178*** (1.204)
Financial development	9.234** (4.541)
Domestic credit provision	0.024* (0.013)
Observations	598
R^2	0.756
Adjusted R^2	0.729
F Statistic	118.877*** (df = 14; 536)

Note: Averages with standard errors in parentheses. Significance levels: *p<0.1; **p<0.05; ***p<0.01

for incentive-based instruments, namely credit allocation, green bonds, and prudential climate risk management, but no effect for informational instruments, namely climate stress testing and green finance guidelines. Interestingly, other disclosure requirements (for non-FIs) show a negative relationship with RE capacity additions, raising question marks about the effectiveness of corporate disclosures. These findings suggest that some but not all GFMP can accelerate the low-carbon transition, and thus, serve as a complementary pillar to conventional climate policy.

Reviewing the key control variables of the main specification (Table 3, Column 1), significant positive coefficients are identified for GDP per capita, population, financial development, and the share of domestic credit provision. Aligned with conceptual expectations, these factors are positively associated with countries' RE development. In turn, unsurprisingly, emissions intensity is negatively associated with RE capacity additions. Interestingly, I find no significant effect for carbon prices. Considering that higher carbon prices increase the cost of fossil fuel energy sources, making RE deployment relatively more attractive, we would expect a positive relationship. However, given that a country like China, which has the highest

RE capacity, pursues a rather state-led RE expansion and only recently introduced carbon prices at relatively low levels around 10USD/tCO2e, the expected relevance of carbon prices weakens in the context of this study.

5.2 Quantile regression results

Quantile regression results describe the relationship between the variables of interest at different points of the distribution of the dependent variable (i.e., RE capacity additions), ranging from the 10th percentile to the 90th percentile. This provides conditional effects and a richer understanding than standard OLS regression, which estimates average effects for the full distribution.

Table 6: Quantile-based results

	Dependent variable: RE capacity additions								
	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
GFMP stock	0.069***	0.110***	0.122***	0.141***	0.148***	0.168***	0.159***	0.188***	0.188***
	(0.010)	(0.028)	(0.021)	(0.022)	(0.020)	(0.024)	(0.033)	(0.033)	(0.048)
GDP per capita	0.00001	0.00003	0.00005***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***
	(0.00001)	(0.00002)	(0.00001)	(0.00001)	(0.00001)	(0.00002)	(0.00002)	(0.00003)	(0.00003)
Population	0.033***	0.056***	0.056***	0.061***	0.054***	0.053***	0.050***	0.042***	0.043***
	(0.005)	(0.016)	(0.004)	(0.010)	(0.010)	(0.007)	(0.007)	(0.005)	(0.006)
Emissions intensity	−7.000***	−10.120***	−10.310***	−9.814***	−9.074***	−10.260***	−8.156***	−6.574**	−5.179
	(1.308)	(2.811)	(1.196)	(1.980)	(1.892)	(2.583)	(2.723)	(3.288)	(4.908)
Carbon price	0.003	0.0003	−0.0003	0.001	−0.001	−0.002	−0.001	0.003	−0.004
	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)	(0.004)	(0.004)	(0.004)	(0.009)
Inflation	0.004	0.003	0.004	0.007	0.006*	0.0004	−0.005	−0.006	−0.013
	(0.004)	(0.003)	(0.004)	(0.008)	(0.004)	(0.008)	(0.011)	(0.020)	(0.030)
Regulatory quality	0.577***	0.513**	0.480***	0.357*	0.257	0.316	0.104	0.177	−0.482
	(0.170)	(0.239)	(0.162)	(0.202)	(0.170)	(0.209)	(0.299)	(0.305)	(0.528)
Financial development	−0.254	−0.913	−0.974	−0.239	0.410	1.695**	1.304**	1.798**	2.046
	(0.447)	(0.740)	(0.659)	(0.768)	(0.735)	(0.817)	(0.600)	(0.710)	(1.759)
Domestic credit provision	0.002	0.005	0.004*	0.006**	0.009***	0.010***	0.008**	0.007*	0.013**
	(0.001)	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)	(0.004)	(0.004)	(0.006)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	598	598	598	598	598	598	598	598	598

Note: Averages by quantiles with bootstrapped standard errors in parentheses. Significance levels: *p<0.1; **p<0.05; ***p<0.01

The pattern of GFMP coefficients across quantiles indicate several important findings (Table 6). First, confirming aggregate results of the TWFE model in Section 5.1, there are consistent positive effects at the 1% level within the magnitude of 0.07 to 0.19 gigawatt RE capacity addition per GFMP. This implies that GFMP are effective in scaling up RE independent of countries' current level of RE deployment. Second, effects show a high degree of heterogeneity, as GFMP has a stronger positive effect on RE capacity additions in higher quantiles. So, GFMP effectiveness seem to increase with existing levels of RE adoption. The effect is about 2.7 times larger at the 90th percentile (0.19) compared to the 10th percentile (0.07). Noteworthy, the model reveals a non-linear impact, underscoring the importance of obtaining conditional estimates across quantiles (Figure 6). The steepest growth in effect, a sharp initial increase, occurs between Q10 and Q20, after which there is a moderate and stable increase in effect size from Q20 to Q60. From Q60 upwards the increase levels off, with the coefficient slightly fluctuating around a plateau before flattening out from Q80 to Q90. This suggests that countries with established RE sectors see stronger benefits from adopting GFMP, while the initial impact may be modest in countries with lower RE deployment. Thus, an important insight is that additional policy measures supporting the maturing of energy markets in countries that are at an early-stage of the low-carbon technology pathway can help to reap higher benefits from GFMP implementation. Thus, complementary RE-supporting policy action, for example in the fiscal space, seem to reinforce impacts and generate synergies that enhance the effectiveness of GFMP in fostering RE deployment. Another interesting observation is that of the control variables, regulatory quality shows a significant positive effect only for the 10th to 40th percentiles. Hence, quality of regulation plays a relatively larger role in increasing RE capacity in countries with low levels of RE. So, in addition to adopting GFMPs, policymakers should explore ways of enhancing their ability of policy enforcement. This underscores the importance of sound institutional capacity in bringing about socially beneficial outcomes, such as an orderly low-carbon transition.

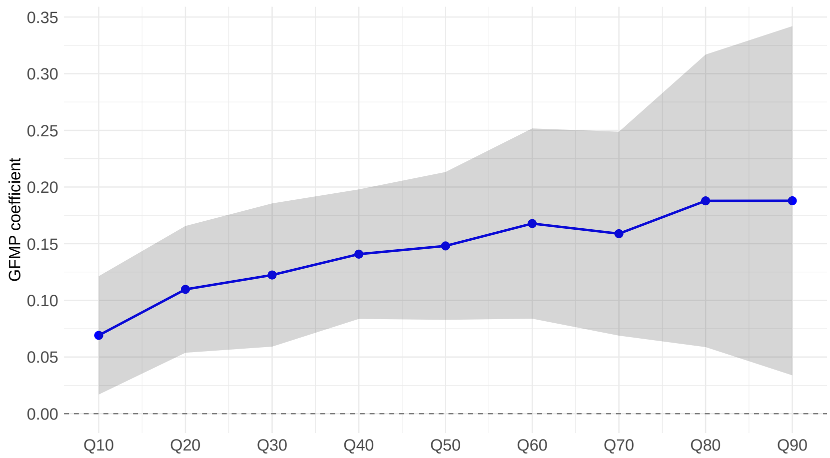

Figure 6: GFMP effects by quantile

Note: Effect of increasing GFMP stock by one policy on RE capacity additions (gigawatt) for the 10th to 90th percentile. Shaded area shows the confidence interval with bootstrapped standard errors.

5.3 Limitations and contribution

This study provides valuable insights into the impact of GFMP on the low-carbon energy transition. However, certain limitations should be acknowledged. For example, distinguishing between short-term and long-term effects of GFMP may oversimplify the time lag dimension between policy adoption and effect, thereby overlooking more granular temporal dynamics in the economic transmission of GFMP. Moreover, when investigating the effectiveness of individual instruments, I do not consider potential interactions and synergies between them. As such, the type-specific analysis presents a static rather than dynamic perspective on existing policy mixes.

I contribute to the literature in three respects. First, I provide an early empirical assessment of GFMP's real-economy impacts and shed light on the heterogeneity of outcomes, providing a deeper understanding of the effectiveness of different policy instruments in driving RE outcomes beyond theoretical models. Second, I provide a structured GFMP index, which to my knowledge is the most up-to-date stocktake of countries' GFMP actions, and can be utilised to investigate other relevant transition outcome variables that are beyond the scope of this study. Third, the coverage of major economies, representing 75% of global emissions and 82% of world GDP, offers a comparative perspective and high policy relevance.

6 Conclusion

This paper has shown that GFMP can promote the transition to a low-carbon economy. In the aggregate dimension, I find a positive effect of GFMP on RE capacity additions, a key indicator of countries' transition performance. When distinguishing between short-term and long-term effects, adopting a GFMP has a statistically significant positive effect on RE capacity additions over the long-term, but not the short-term. Zooming into policy instruments, I find positive effects for incentive-based instruments (credit allocation, green bonds, prudential climate risk management), but not for informational instruments (climate stress testing, green finance guidelines, disclosure requirements). Moreover, quantile analysis reveals a high degree of heterogeneity of effects, with the impact at the 90th percentile being 2.7 times larger than at the 10th percentile. Thus, countries with already higher levels of RE adoption experience stronger benefits from adopting a GFMP than countries with relatively immature RE markets.

This empirical analysis gives rise to several policy implications. Given that (some) GFMP are found to be effective, but only deliver effects in the long-term, GFMP should be more actively and rapidly developed. Put simply, to contribute to tomorrow's decarbonisation, policies need to be implemented today. Moreover, while informational measures may align closer with conventional market neutrality principles, incentive-based instruments seem to be more effective in delivering real economic impacts. Accordingly, policymakers wishing to promote an orderly transition should re-think current policy design. An implication from the heterogeneity of effect sizes across quantiles is that policymakers in countries at an early stage of the RE pathway should consider complementary measures that enable maturing of RE markets, and thus higher benefits from implementing GFMP. Lastly, considering the diversity in GFMP adoption across countries, there is a case for increased policy cooperation and harmonization, for example via initiatives like the NGFS or Coalition of Finance Ministers for Climate Action. Avenues for further research include, for example, event study analyses of individual GFMP, and examining effects on other transition-relevant indicators such as green innovation or low-carbon consumption.

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Appendix

Table 7: Mean RE capacity (additions) by country

	Country	RE capacity	RE capacity additions
1	Australia	8.7	1.7
2	Austria	2.4	0.3
3	Belgium	3.8	0.5
4	Brazil	8.3	2.1
5	Canada	7.8	0.9
6	China	165.5	33
7	Denmark	4.9	0.3
8	Finland	1.1	0.3
9	France	12.3	1.7
10	Germany	59.3	5.6
11	Greece	3.3	0.4
12	India	29.3	4.6
13	Italy	16.5	1.6
14	Japan	25.5	3.6
15	Mexico	3.8	0.7
16	Netherlands	6	1.4
17	Norway	1.2	0.2
18	Russia	0.5	0.2
19	South Africa	2.4	0.4
20	South Korea	4.8	1
21	Spain	23.3	2.1
22	Sweden	4.5	0.7
23	Switzerland	1	0.2
24	Turkey	5	0.9
25	United Kingdom	15.2	1.9
26	United States of America	77.4	11

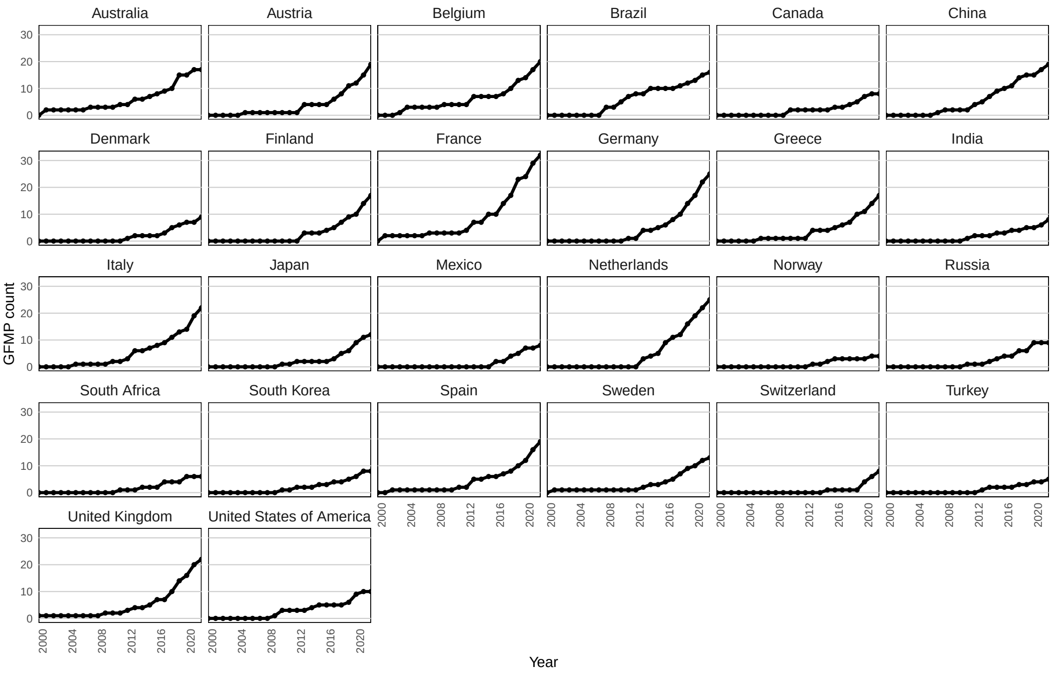

Figure 7: GFMP adoption by country

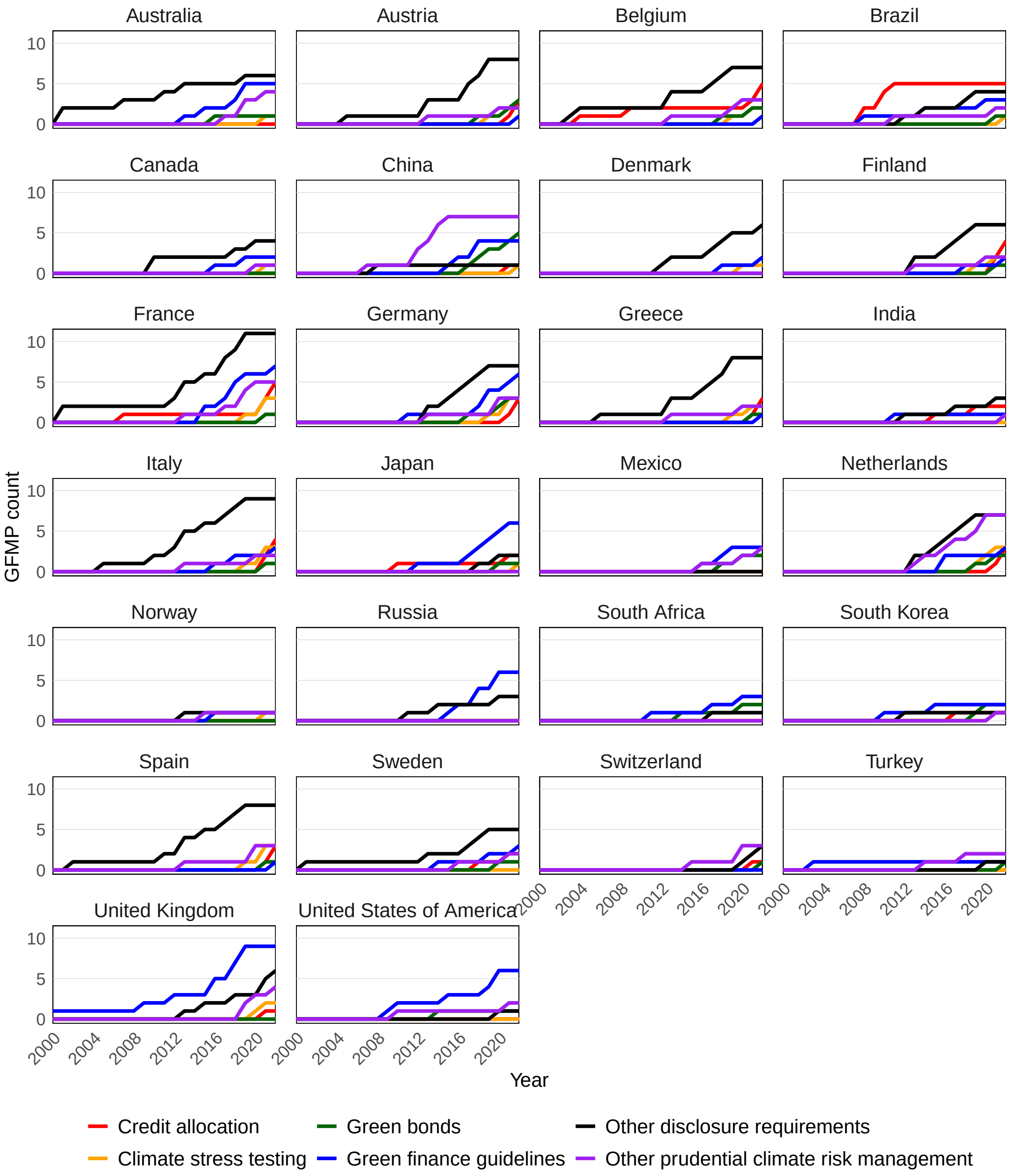

Figure 8: GFMP adoption by country and policy type