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Analyzing the relationship between energy efficiency and environmental and financial variables: A way towards sustainable development

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ABSTRACT

The literature has mainly relied on an annual and short span of data to analyze the relationship between energy, environmental and financial indicators. This study analyzes the relationship between energy efficiency, energy research, pollution mitigation, and FinTech by applying two novel methods-the causality test in the frequency domain [11] and the causality test in the time domain (Shi et al., 2018; 2020)-on the daily data from June 17, 2016 to November 16, 2021. Empirical results from the frequency domain test report that pollution mitigation temporarily causes energy efficiency only in the short run while energy efficiency Granger causes it in the short, medium, and long run. Furthermore, energy efficiency can predict FinTech in the short, medium, and long-run; on the other way, FinTech Granger causes energy efficiency in the long and medium run, suggesting a permanent causality relationship. Empirical results from the time-varying test show a bidirectional relationship between energy efficiency, and environmental and financial variables, especially with very high significant episodes around the recent pandemic collapse. Policymakers should promote the launch of financial technologies that will provide finance through green bonds for energy efficiency improvements as well as energy efficiency improvements for pollution mitigation. Further policy implications are discussed in the study.

1. Introduction

Support for sustainable business is growing in both developed and developing economies [1]. Moreover, consumers believe brands bear as much responsibility for positive and sustainable change as governments [2]. Thus, a business must commit to protecting nature and natural systems [3]. The adoption of financial technologies (or FinTech) may impact consumption, savings, and investment decisions, therefore, affecting the production and use of renewable energy [4]. FinTech enables and increases energy efficiency [5,6], and mitigates harmful pollution effects [7,8]. Consumers are increasingly demanding ecological or environmentally friendly products to ensure a sustainable lifestyle and prevent global warming and its negative impacts on the planet [9]. By perceiving firms to be more socially responsible and aware of environmental issues, consumers become more willing to buy the products of these firms at higher prices [10]. While noticing this, firms strive to differentiate their products and brands resorting to green marketing campaigns and modernizing their technologies. This leads to increased energy efficiency, energy research, and pollution mitigation. However, consumers will only trust this advertisement and consume more of these products if firms are honest and products accurate [9]. An efficient green economy boosts low energy consumption, and lowers pollution and emissions, turning to be a channel to achieve sustainable development [2].

Following the [11]; FinTech is the set of digital financing technologies. These include mobile payment platforms, artificial intelligence, big data, IoT, blockchain, and cryptocurrencies (other definitions are provided by Ref. [4]. FinTech has been constantly growing [12] and promoting the unlocking of green finance

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technologies [13]. These innovations were able to reduce the cost of capital [14], improving efficiency, in both scale and speed [12]. Thus, FinTech is no more than financial technologies [4] influencing renewable energy. It also reduces energy intensity and pollutant emissions, favoring sustainable global economic growth [5]. FinTech enhances the positive impact of green finance on the ecological environment and economic structure [15]. However, the literature also reports that FinTech has limited effects on the relationship between green finance and economic efficiency [15]. Decreasing information asymmetry for investors, promoting efficiency, valuing and preserving natural assets, and promoting sustainable lifestyles, FinTech accelerates the development of green finance (greener investment opportunities and financial returns) and sustainable high-quality economic development [16,15]; [9]). Jointly, FinTech and green finance promote green economic growth [17]. [4] highlight the importance of financial technologies as a significant positive driver of renewable energy for OECD countries. The use of renewable energy sources and their implementation by firms is captured through the energy research index in the present article. As well, technological innovation, an enhancer of financial technologies, plays an important role in reducing environmental pollution and increasing economic development [18]. Following [19]; energy efficiency and clean energy resources were crucial in reducing greenhouse gas emissions in 66 developing countries from 1990 to 2014. Green financing techniques help to clean the environment and promote green economic growth in G7 and E7 countries [20]. For [21] financial development promotes energy innovation and improves environmental quality (reducing greenhouse gas (GHG) emissions) for OECD countries [22]. provides a literature review of the energy efficiency concept within social sciences, stating that it allows to save energy and mitigate climate change.

It is evidenced in the literature that renewable policies are the most effective in terms of climate goals at a local scale, whereas energy efficiency policies alone are ineffective [23]. Additionally, public spending on the R&D of green energy technologies enhances a sustainable green economy through technology-oriented production activities, despite being different effects for different countries [24]. Technological progress can improve energy efficiency [5], being crucial for the transition to a low carbon economy [7,8]. Energy efficiency investment projects are fundamentally financed by bank loans although being an inadequate supply of funds [25], and self-financing is neither adequate nor sufficient [6]. question if sustainable economic and financial development is possible to be achieved while reducing greenhouse gas emissions in OECD countries finding that it is true if energy efficiency is increased. Even so, contemporary economies are deficient in the raise of financial resources able to ensure the correct availability of funds necessary for energy efficiency [26].

Within this context, this study explores the causality effects between energy efficiency and financial technology, and environment-related indicators. Thus, it intends to deepen the existent relationship between the energy efficiency index, which tracks companies that increased energy efficiency, the pollution mitigation index, tracking companies producing goods and services that reduce pollution, the energy research index, composed of companies that sustainably manage energy use or actively engaged in reducing greenhouse gas emissions and expanding the use of renewable energy sources, and the FinTech index, tracking companies engaged in financial technologies. The literature review does not allow to observe any other article focusing on the subject, despite the proven existent relationships between these four indicators. Moreover, the daily time series data used allows a better understanding of the interactions between time series and to explore the current evolution of the involved firms in financial markets where these indexes are traded, reflecting companies' and countries' evolution in this respect.

This study contributes to the existent literature in several different ways. First, this is the first study that explores the relationship between four non-well-explored indexes for the energy-finance-environment nexus; namely, energy efficiency, pollution mitigation, energy research, and financial technology (FinTech). It was identified in the literature a research gap concerning the role of FinTech over green development [17], especially that respect to energy efficiency, pollution mitigation, and energy research. Second, this study adds to the literature by using novel methods; namely, the causality test in the frequency domain [27] and the causality test in the time domain [28,29]. The main difference between the frequency-domain approach and the time-domain approach is that the frequency-domain approach tests the degree of a specific time-series variation and the 'time-domain' approach tells us when a certain variation takes place within a particular time series [30]. Third, this study explores a very recent data period, resorting to daily data spanning from June 17, 2016 to November 16, 2021, allowing us to include the recent market impacts of the worldwide pandemic. All these indexes jumped upwards from January 2020 onwards and still keep their ascending trend in the market, evidencing a clear common pattern among them and justifying the need to explore this relationship.

The rest of the article develops as follows. Section 2 exposes the data used in this research, whereas section 3 exposes and explores the methods and empirical findings. Finally, section 4 concludes this work by pointing out directions for future research and presenting policy implications derived from the exposed results.

2. Data

This research study uses the daily data for energy efficiency, energy research, pollution mitigation, and financial technology spanning from June 17, 2016 to November 16, 2021. In detail, "*Energy Efficiency Index* is a primary sector index of the Green Economy Index designed to track companies that dramatically increase energy efficiency inclusive of the subsectors energy management, energy storage, smart grid and green IT; *Pollution Mitigation Index* is a primary sector index of the Green Economy Index designed to track companies producing goods and services that reduce pollution from conventional industrial processes, power plants and other emitters; *Energy Research Index* is composed of companies that manage energy use in a sustainable manner or that are actively engaged in facilitating the transition to a more sustainable economy through the reduction of greenhouse gas emissions and the expanded use of renewable energy sources; *FinTech Index* is designed to provide an equity benchmark for investors to measure and track the performance of companies engaged in Financial Technologies, primarily in the areas of software and consulting, data and analytics, digital payment processing and transfer, and payment transaction-related hardware." The data were collected from Datastream (www.refinitiv.com) and can be made available upon request for replication purposes. Table 1 shows the descriptive statistics while Fig. 1 represents the trends of the variables under consideration. They show a high volatility-up and down over

Table 1
Descriptive statistics.

	Obs	Mean	Std. Dev.	Min	Max
EnergyResearch	1356	1435.422	442.4342	921.44	2518.037
EnergyEfficiency	1356	1899.498	408.7961	1140.58	2930.7
PollutionMitigation	1356	1767.512	347.2417	1167.73	2632.32
FinTech	1356	367.5241	105.3752	203.83	588.62

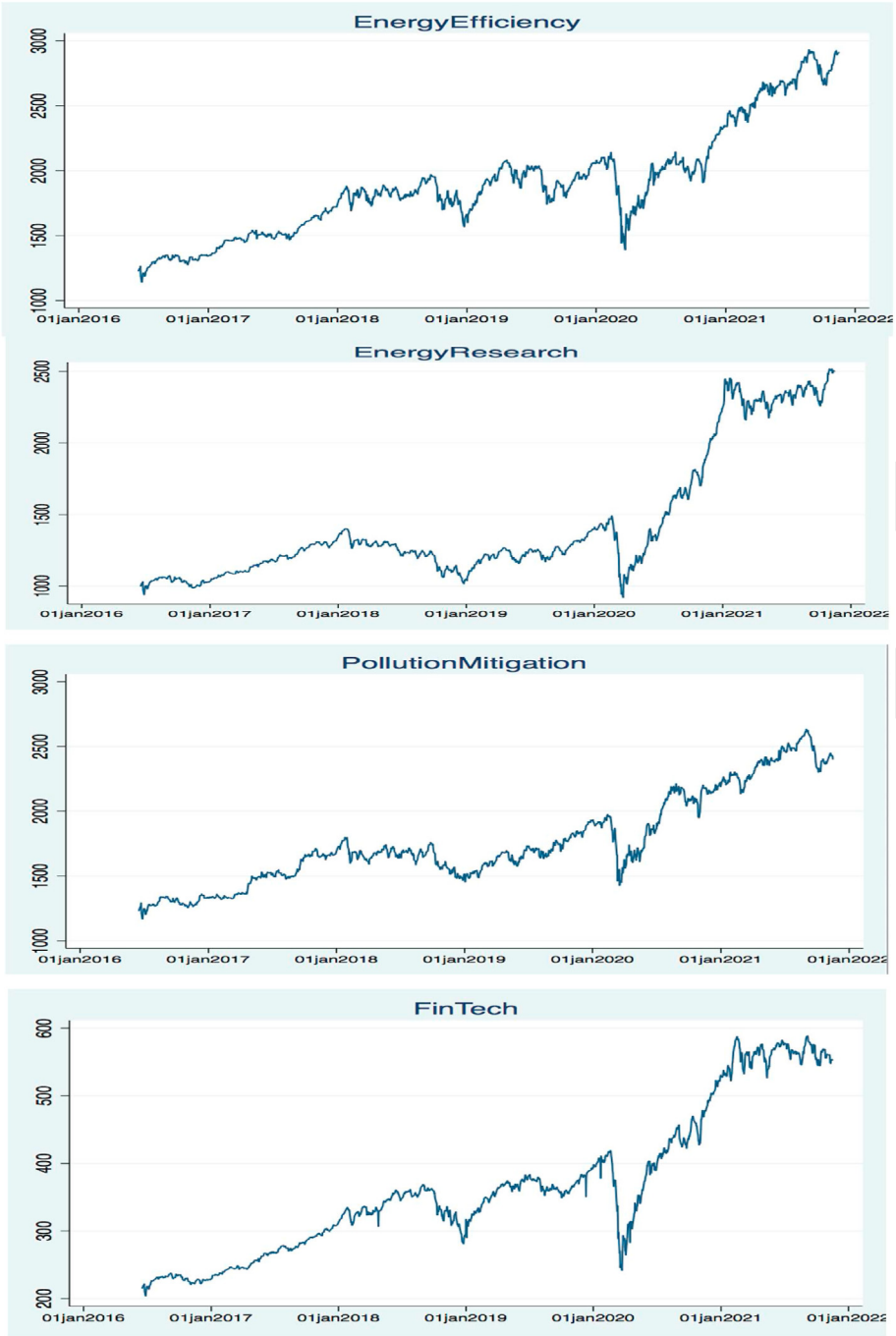


Fig. 1. Trends of the analyzed variables.

the period, especially a big fall at the beginning of the spread of the COVID-19 pandemic.

3. Methods and empirical results

3.1. Breitung–Candelon frequency-domain test

[27] frequency domain causality test enables capturing the causality in the short, medium, and long term. In this paper, the causal effects of energy efficiency, energy research, pollution mitigation, and FinTech are estimated at different time frequencies using worldwide indexes. The causality relationship between the variables is examined at frequencies 2–3, 1–2, and 0–1, which display short, medium, and long-term relationships, respectively. In addition, 2–3 is considered a temporary causality, whereas 0–1 is permanent causality. The time-domain method points to a time series when a particular change occurs in a time series. The frequency-domain approach investigates the extent of a specific variation in time series allowing the elimination of seasonal variations even in small samples. The frequency-domain test marks non-linear patterns and causality episodes while permitting the identification of short, medium, and long-term causalities.

Fig. 2 presents the results of [27] frequency domain causality test results. The first panel suggests that the energy efficiency index

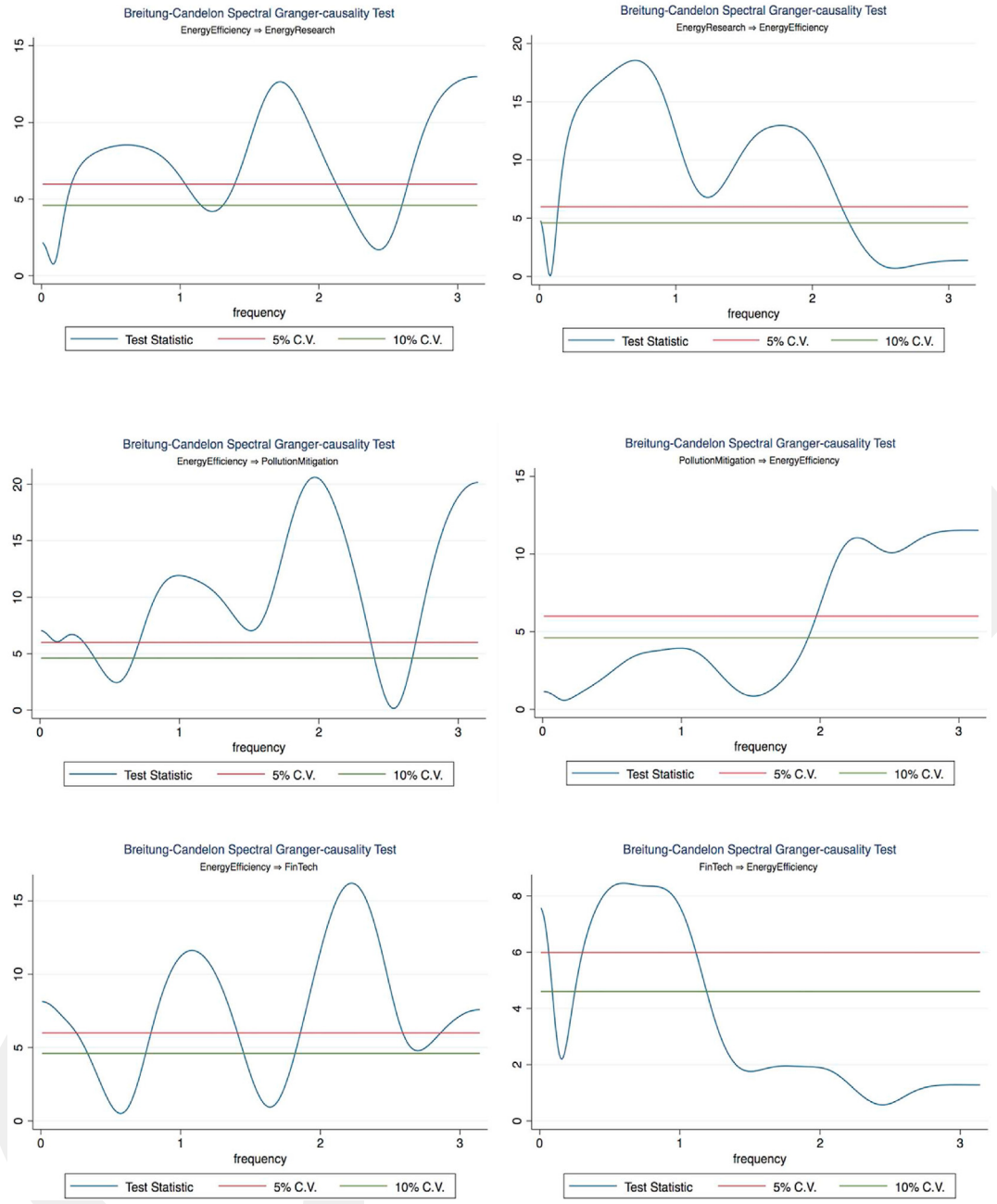


Fig. 2. Breitung–Candelon frequency-domain spectral causality test.

Granger causes energy research index in the short, medium, and long run. Companies that are focusing on boosting their energy efficiency are more inclined to do energy research. The literature also notes that the gains from energy efficiency can effectively be allocated to energy research [31]. In fact, at both the national and regional levels, energy efficiency is an important policy strategy. Considered a cost-effective way to save energy, it allows for mitigating climate change [22], and the energy research index is composed of companies that sustainably manage energy use or are actively engaged in reducing GHG emissions and expanding the use of renewable energy sources, confirming previous authors findings. The second panel shows that the energy research index drives the energy efficiency index in all periods. The finding implies that energy research can predict energy efficiency in the short, medium, and long-run which suggests energy efficiency is caused by the innovations and research in energy. This finding is also reported by Ref. [5] on a large context of countries, and by Ref. [32] on China. Considering a sample of the 24 highly innovative OECD countries [8], studied the technological innovation effect on the performance of energy efficiency of neighboring countries with annual data from 1994 to 2013 [8]. suggest the development of domestic R&D capacity to ensure the growth of innovation-based infrastructures capable of promoting sustainable environmental and energy management.

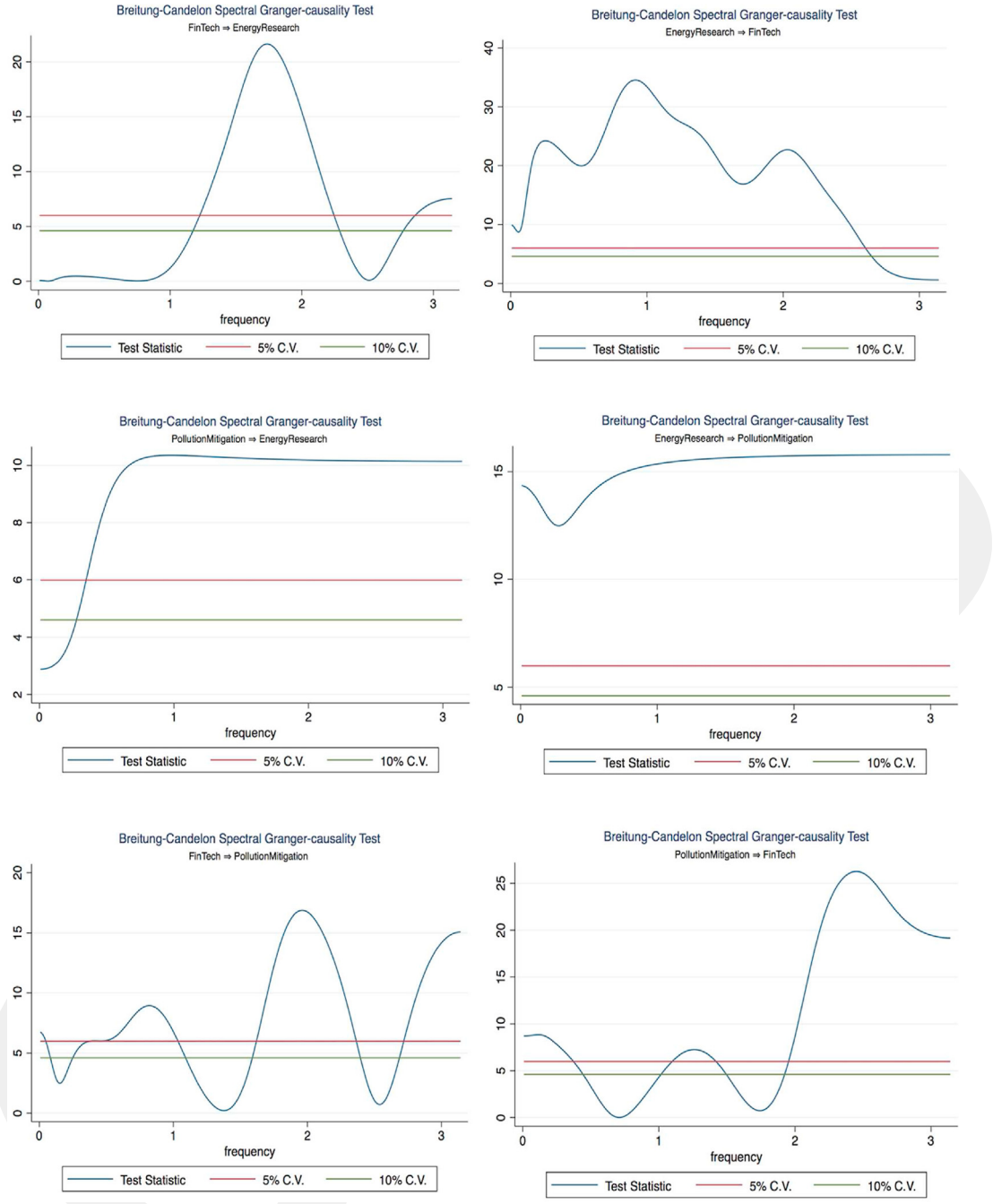


Fig. 2. (*continued*).

Energy efficiency index is found to Granger cause pollution mitigation index in the short run, medium run, and long run. The literature notes the significant impacts of improving energy efficiency on decreasing pollutant emissions in the iron and steel industry [33]; brickmaking industry [34]; and incineration industry [35]. The pollution mitigation index impacts the energy efficiency index with a temporary causality, only in the short run [36]. also confirm this feedback relationship between energy efficiency and pollution mitigation. Using energy efficiently drives lower energy consumption, the substitution of fossil fuel sources for renewable ones, and leads to pollution mitigation [37]. For a sample of 29 European countries [37], found a long-term causal relationship between energy efficiency and GHG emissions, where the quantity of GHG emissions decrease with energy efficiency improvements, supporting also our findings. The energy efficiency index can predict the FinTech index in the short, medium, and long run. On the other hand, FinTech index Granger causes energy efficiency index in the long and medium run, suggesting a permanent causality relationship. The FinTech industry has significant attributes to increase energy efficiency such as its role in allocating resources to green finance impact energy efficiency investments [38,39,40], and thus, the digitalization of financial services provides potential to trigger the adoption of energy-efficient technologies [26].

FinTech index drives energy research index between the frequencies of 1.3−2.3, which is in the medium run. An episode of significance is also noted in the short run at frequencies higher than

2.9. Energy research index Granger causes FinTech index in the medium and long term, indicating a permanent relationship. However, the null hypothesis is rejected at 5% and 10% significance levels for the short term. Energy research expenditures require a huge amount of investments, which are not financed with traditional terms due to the higher risks inherent in these investments. Thus, this necessity granger causes the rise of non-traditional forms of finance such as cryptocurrencies such as NRGcoin, and blockchain-based renewable energy certificates [4], which are newly created instruments by FinTech. FinTech influences renewable energy [4], by reducing energy intensity and pollutant emissions [5].

A causal relationship is noticed between the pollution mitigation index to the energy research index in the short, medium, and long run. The reverse causality is from the energy research index to pollution mitigation also valid for all frequencies. Pollution mitigation policies and pollution mitigation activities cause energy research expenditures. Thus, investors who are considering holding these two indexes in their portfolio could expect a two-way Granger causality and could base their estimations accordingly. If the energy research index simultaneously firms engaged in reducing GHG emissions and expanding renewables usage, the bidirectional causality was expected as also concluded by other authors [16,15]; [9]. Jointly, FinTech and green finance promote green economic growth [17], leading to environmental benefits [4]. There is proof of Granger causality from FinTech to pollution mitigation in the short, medium, and long term; which is also valid from the pollution mitigation to FinTech in the short-medium, and long term; strikingly significant specifically in the short term. Action to mitigate pollution will trigger means of financing these actions. FinTech will trigger pollution mitigation activities for the firms. These relationships also suggest that investors could estimate these two indexes since they have a feedback relationship. Governments and policymakers should support not only environmentally sustainable energy sectors [4] but for all the economic activity sectors, fostering, promoting, and encouraging the use of financial technologies and green financing for new environmentally friendly projects [13,12].

3.2. Time-varying causality test

The time-varying causality test proposed by [28,29] examines the alternate hypothesis of parameters being significantly over the whole or a point of time. The recursive evolving algorithm is calculated on a subsample of Wald statistics and is based on the recursive calculation of the related test statistics, in a backward expanding sample sequence in which the final observation is the observation of interest. The procedure is called recursive evolving algorithm as the inference regarding the existence of causality is based on the final observation "which depends on supremum taken overvalues of all the test statistics in the entire recursion". The recursive evolving procedure endogenously determines the change points i. e the date of origin and collapse of causality and change in direction of causality within the sample data without the need for detrending data.

Fig. 3 presents the results of the time-varying recursive evolving Granger causality[1] Table 2 summarizes the outcomes of Breitung–Candelon frequency-domain test and time-varying recursive evolving Granger causality test results. The results display a dynamic causal relationship between energy efficiency, energy research, FinTech and pollution mitigation indexes that becomes more significant during the pandemic period by the rejection of the null hypothesis of no causality since the Wald statistics exceed the 5% critical value sequence. Thus, financial markets became more synchronized at this period, highlighting the need to evaluate their joint behavior. These results contradict the findings of [41] stating that declining global economic conditions might obstruct the positive trend of green and low carbon energy progress. This could also mean that more intelligent policies have been implemented in the private sector and society converting the Covid-19 menaces into great opportunities for renewables, energy efficiency, pollution mitigation, and sustainable growth. Our results point to the significant role of FinTech in this context providing bidirectional causalities in the short, medium, and long run.

Energy research Granger causes the Energy Efficiency index and this impact is visible starting by the end of 2019 to the most recent observation. The pandemic turbulence strengthened this causality impact from energy research to energy efficiency. We also notice a causality from energy efficiency to energy research, but the causality seems to fade, becoming insignificant with the start of the pandemic. This finding is also confirmed by Ref. [42] by addressing the energy efficiency investments to be inherently risky and a wide range of factors impact these investments and energy efficiency is deeply influenced by the pandemic. Interestingly, the energy efficiency index is also Granger caused by the pollution mitigation index and FinTech index, especially with very high significant episodes around the COVID-19 collapse. The index seems to be explained by the movements of the other sustainability indexes under scrutiny during more turbulent times. COVID-19 have increased the uncertainty and display negative and unpredictive outcomes in global economy that increase the confusion and uncertainty among investors [43]. On the other hand, at the start of the observation period, the causality test statistics from pollution mitigation to energy efficiency are barely significant, limited by very few observations. FinTech index Granger causes the energy efficiency significantly in and out through the investigated period, but with perseverant impact after the pandemic. Energy research index is Granger caused by pollution mitigation and FinTech indexes alongside with energy efficiency index, yet the causality impact of these indexes does not coincide very often. The Granger causality of pollution mitigation is visible throughout the period with significant impacts up to 2-month periods at maximum. However, FinTech's causality is more persistent starting with the period from the beginning of 2019 to the beginning of November 2020. Pollution mitigation is Granger caused by energy efficiency, energy research, and FinTech indexes with statistical significance at almost overlapping periods. The statistical significance of the Wald tests intensifies at the end of 2018s, around June 2019 until March 2020. Energy efficiency, on the other hand, Granger causes pollution mitigation with higher statistical significance starting with November 2020. Energy efficiency Granger causes FinTech index with significance over long observation periods along the analyzed horizon. The significance is scattered from 2018 to March 2020. The significance disappeared with the start of the pandemic and the significance of this test is visible after December 2020. The FinTech index is Granger caused by the energy research index very significantly for most observations under analysis remarkably after 2019. The pollution mitigation index on the other hand displays limited statistical significant episodes around April 2017, February 2019, Dec 2019, September–November 2020, and August 2021 [44]. report similar outcomes regarding the spillover between FinTech and other financial assets like gold, global equity index, crude oil, US Dollar and bitcoin and note that FinTech and bitcoin act as the net receipient of volatility shocks during the COVID-19 pandemic.

[1] Energy efficiency, energy research, pollution mitigation and financial technology indicies are stationary at their first differences, implying that they are I(1) upon applying several unit root tests. To save space, the unit root results are not reported in the text but available upon request.

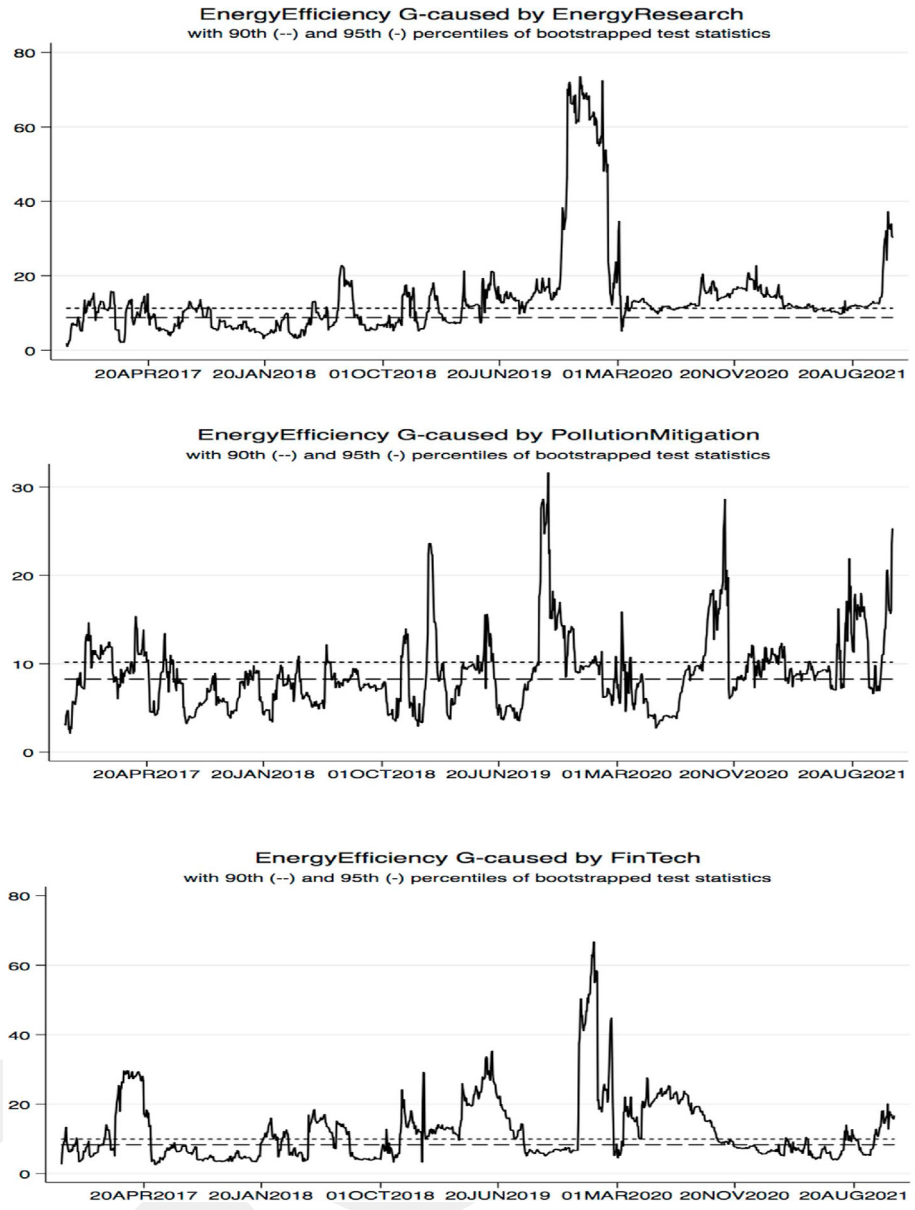
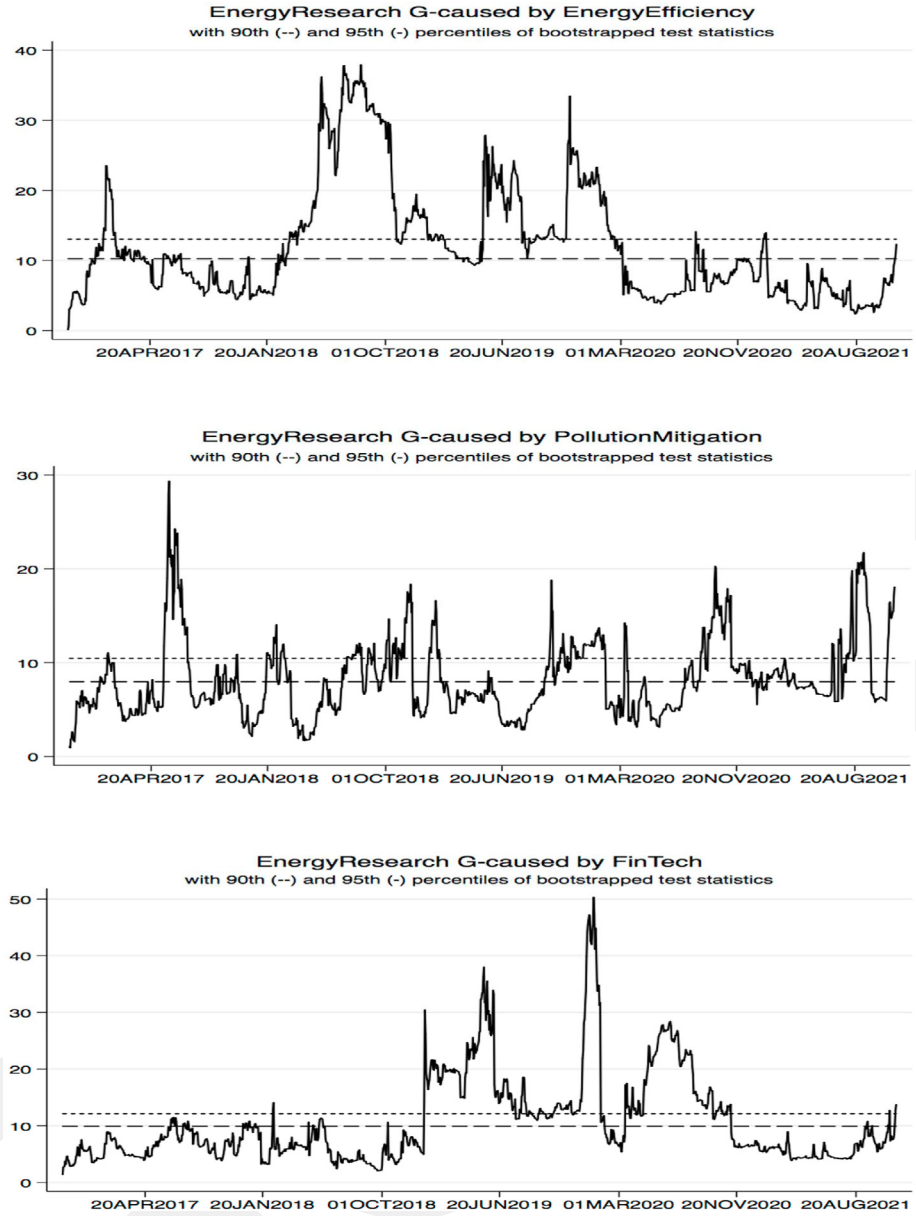


Fig. 3. Time-varying causality test.

This finding point to the fact that these instruments do not display safe heaven properties and the industries which are dependent on FinTech might be highly susceptible to shocks. Overall, the results point to significant intensifications among these indices during the COVID-19. It is evident that the pandemic created significant challenges alongside with opportunities to change our trajectory by changing our work lives as shifting to digitalization and reducing fossil-fuel consumption. Moreover, it lead to shifts in political responses and the need for increased securitization is likely to accelerate sustainable practices [45], which can be witnessed in our empirical results.

Some policy measures should be conducted in face of these results. It is known that the priorities for public spending include "support for private sector green innovation and infrastructure, development of smart grids, transport systems, charging station networks, and sustainable cities" [46]; p.685). Results here provided evidence of the significant role of financial technologies in this context, whereas these policies could be enhanced by pricing carbon and pollution and removing fossil-fuel subsidies. These would give the necessary means to increase the financing strategy of FinTech to promote sustainable green growth worldwide. Only then we would be able to accelerate the transition, raise revenues for the necessary public investments (provided FinTech and technologies are more expensive, [12], and lower the overall cost of the green transition. Additionally, air pollution levels decreased during the pandemic due to global confinements. Thus, through joint efforts, climate change goals can be achieved. However, it should be noted that this was only a temporary relief, impeding that it could be declared a sustainable way of saving the environment [47]. Both green finance and FinTech could be enhancers of pollution mitigation and energy efficiency gains, but this is only possible through the continued betting in energy research [48,26]. Moreover,



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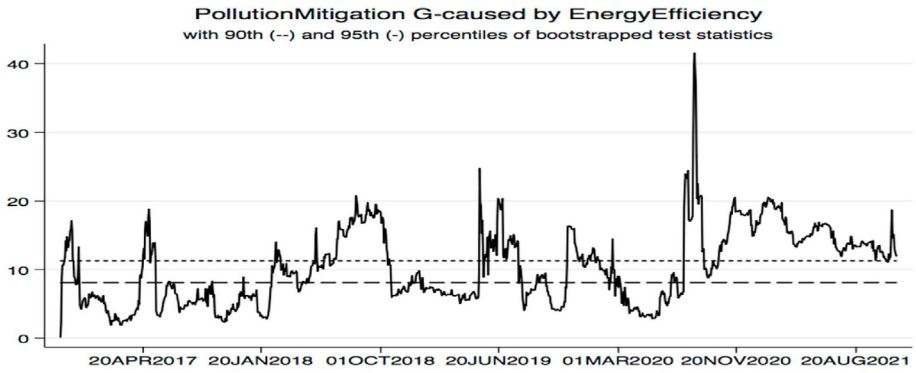
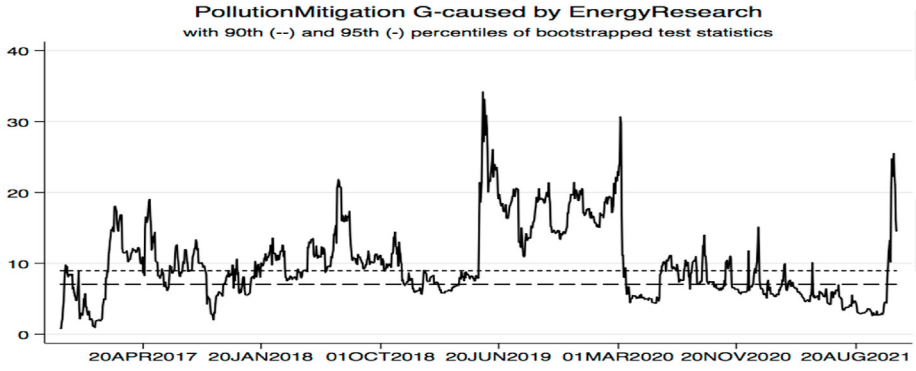
consumers-investors have an important role in these continued interactions among financial indexes and respective evolutions, probably turning more environmental consciousness and awareness, provided they are available to support additional costs ([2]; [9]).

4. Conclusion and policy implications

Given the current condition the world is witnessing regarding environmental deterioration and climate change, it is obvious that financing greener technologies are a big necessity. Many investors, who are seeking ways to invest in those companies that give environmental issues a priority, realize this necessity. Going green is not easy and green investments require a huge number of investments. The increased awareness to promote sustainable companies created means of financing, especially through traditional ways like green bonds and equities and recently through nonconventional ways such as cryptocurrencies using blockchain technologies. The call for investors to advocate sustainable countries has led to many different sustainability indexes all around the world. These indexes act as evidence of the increased interest in cleaner companies.

This paper investigates the relationship between Energy Efficiency, Pollution Mitigation, Energy Research, and FinTech indexes using novel methods, which are the causality test in the frequency domain [27] and the causality test in the time domain [28,29]. The period considers daily data from June 17, 2016 to November 16, 2021. Frequency domain causality test results overall suggest that the investigated indexes mainly have a feedback relationship with a temporary and permanent causality. This suggests that investors consider these indexes as similar investment instruments and thus these indexes can forecast each other both in the short, medium,





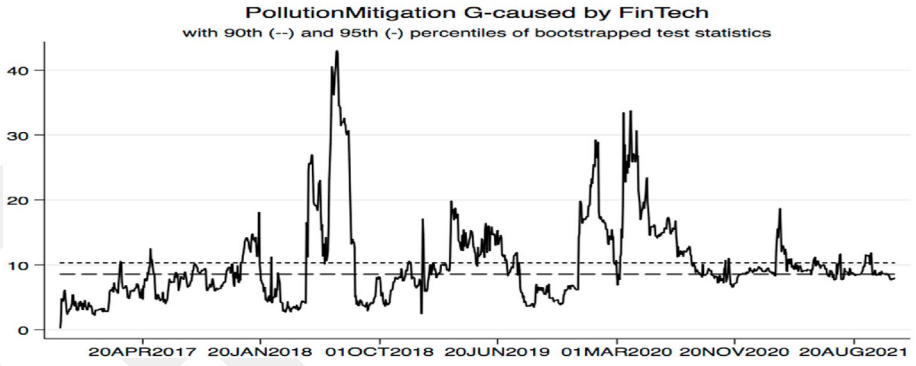


Fig. 3. (*continued*).

and long run. Time-varying recursive evolving Granger causality test results also report a bidirectional relationship between energy efficiency, energy research, pollution mitigation, and FinTech indexes.

The literature points to a technological gap between countries, nowadays still being visible and significant [8]. Our results suggest that energy efficiency is caused by innovations and research in energy. Therefore, policymakers should bet on domestic, and promote foreign, innovative capabilities and technologies, which our results point to for the higher promotion of FinTech technologies to also ensure emission reductions and a sustainable environment. Spillover effects have been proved to be beneficial concerning foreign spread effects [8,5]. As well, this adoption should be considered with the adjustment of human resources able to deal with these new technologies, not only in terms of newly developed tangible capital but also with intangible like FinTech. It was also found a bidirectional long-lasting relationship between FinTech and energy efficiency in empirical estimations. Therefore, policymakers should promote financial technologies which support related assets such as green bonds for energy efficiency improvements as noticed also by Ref. [26].

The results also show that the predictive power of the indexes increases during turbulent times such as the COVID-19 pandemic. This finding suggests the potential benefits of constructing trading strategies by considering the interaction between these indexes. The investors consider these investments in the same asset class and regard them in their portfolios accordingly. Moreover, the increase in the level of these indexes during the pandemic also

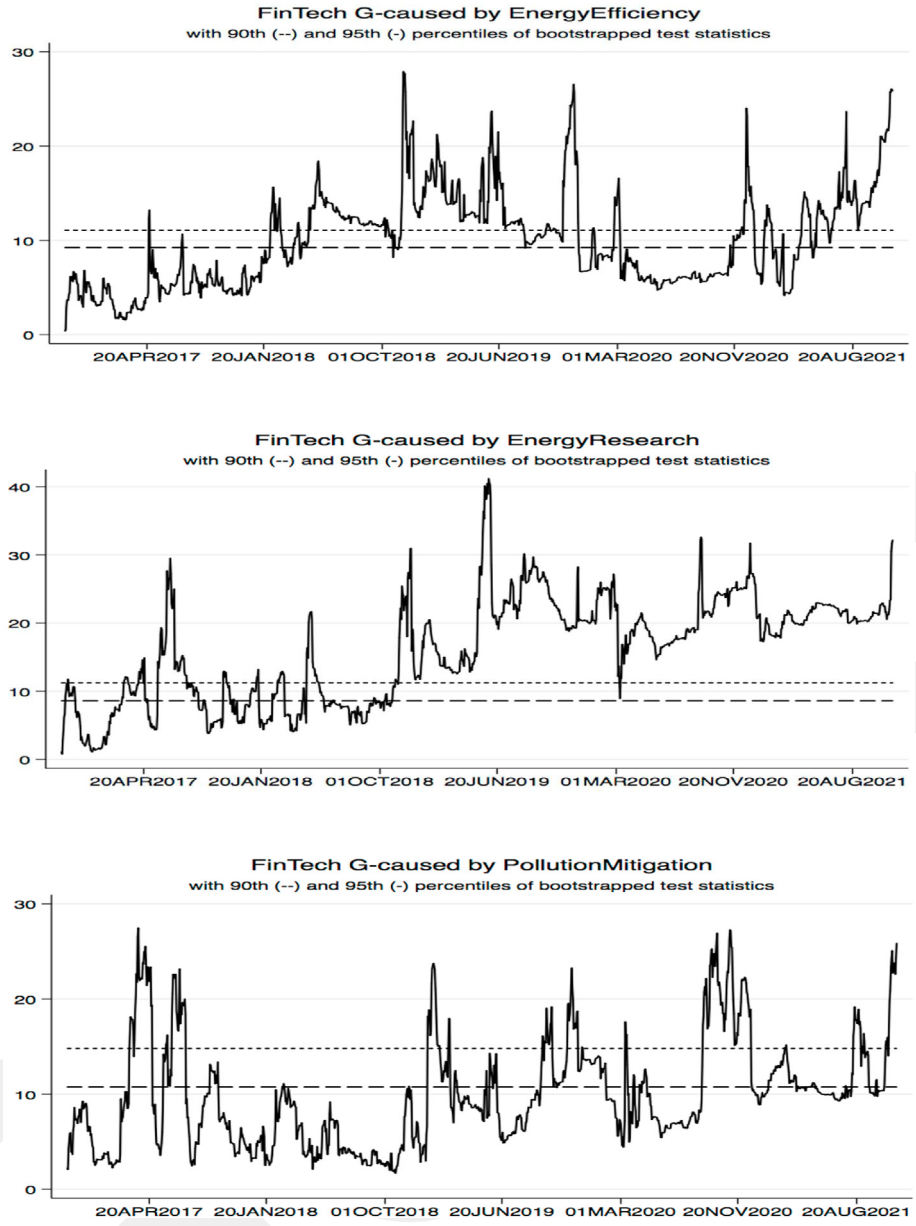


Fig. 3. (*continued*).

displays that these indexes are considered safe assets [49,50]. The results also point to many data points with no causality relationship, suggesting that these indexes could still provide diversification benefits to eliminate the diversifiable risk. The results also may convey information regarding the sustainability practices of the companies covered in these indexes. The predictive power of these indexes to estimate each other suggests that investors value the positive contribution of these companies' activities to each other. Overall, the paper provides solid evidence of the significance of considering these indexes as investment alternatives both for the portfolios of the investors and to ensure sustainable growth. Thus, the existence of the sustainability indexes and indexes that track the positive contribution of the companies to sustainable growth will provide resilient investment alternatives for investors and also promote a sustainable economy, enhancing green finance portfolios and improving sustainable growth, and ensuring environmental quality.

The results discussed previously allow us to state that the pandemic generated great advantages in the link efficiency-environment-sustainability-FinTech. This is so due to the strengthening verified in causalities during this period, especially the role promoted by financial technologies. Thus, other energy sources like cogeneration [51], or any other substitute of oil and natural gas [52], could be financed through green bonds and promoted during turbulent periods given their efficiency and cost-effectiveness for both energy savings and emissions reduction. Overall, policymakers should promote the launch of financial technologies that will provide finance through green bonds for energy efficiency improvements, especially those envisaging pollution mitigation [53,54].

Table 2
Summary of test results.

Direction of Relationship	Frequency-domain test	Time-varying causality test
Energy Efficiency G. caused by Energy Research	+ SR., MR. & LR	+ Clearly visible starting by the end of 2019 to most recent observation.
Energy Efficiency G. caused by Pollution Mitigation	+ SR	+ Intensified around COVID-19 collapse
Energy Efficiency G. caused by FinTech	+ MR. & LR	+ Throughout the whole period but intensified around COVID-19 collapse
Energy Research G. caused by Energy Efficiency	+ SR., MR. & LR.	+ Intensified with the beginning of 2018 to until the burst of pandemic
Energy Research G. caused by FinTech	+ MR.	+ Persistent starting with the period from beginning of 2019 to beginning of Nov 2020
Energy Research G. caused by Pollution Mitigation	+ SR., MR. & LR.	+ Throughout the period but significant impacts last around 2 months
Pollution Mitigation G. caused by Energy Efficiency	+ SR., MR. & LR.	+ Intensifies at the end of 2018, around June 2019 until March 2020
Pollution Mitigation G. caused by Energy Research	+ SR., MR. & LR.	+ Intensifies at the end of 2018, around June 2019 until March 2020
Pollution Mitigation G. caused by FinTech	+ SR., MR. & LR.	+ Intensifies at the end of 2018, around June 2019 until March 2020
FinTech G. caused by Energy Efficiency	+ SR., MR. & LR.	+ Significant almost all periods
FinTech G. caused by Energy Research	+ MR. & LR	+ Significant almost all period with intensity after 2019
FinTech G. caused by Pollution Mitigation	+ SR., MR. & LR.	+ Low significance throughout the observed period. Significance detected around Apr. 2017, Feb. 2019, Dec. 2019, Sept−Nov. 2020, Aug. 2021.

Note: SR: Short run; MR: Medium run; LR: Long run.

This work has limitations, being the main the fact that it resorts solely to worldwide indexes to study the causality relationships. These could be surpassed by the exploration of these limitations in future research. Results could be improved in the future by analyzing country time series and reporting the differences between developed and developing countries. Only then could country-specific policy directions be discussed. Also, it would be easy to observe financial spillover effects and portfolio diversification, for consumers which are becoming more aware of sustainable investments, which are still in their infancy. Greenwashing could be a problem within the development and promotion of green finance technology, and analyzing this effect at the financial market level, studying possible causalities and spillovers would be an interesting study for the future.

Credit author statement

Eyup Dogan: writings, model, supervision; Dilvin Taskin: methodology, writings; Mara Madaleno: introduction, literature review.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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