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RESEARCH ARTICLE

How precious metal and energy resources interact with clean energy stocks? Fresh insight from the novel ARDL technique

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Abstract
To boost the stability of economic and financial aspects along with the apprehensions for sustainability, it is important to promote the development of clean energy stocks around the globe. In the current research, the researchers have examined the impact of oil prices, coal prices, natural gas prices, and gold prices on clean energy stock using the autoregressive distribution lag (ARDL) approach from the year 2011 to the year 2020. The result of daily data analysis specifies that in the long as well as in the short run, gold prices, oil prices, and coal prices have a positive and significant effect on clean energy stock. On the other side, natural gas prices in the long as well as in the short run have a negative and significant effect on clean energy stock. So, the empirical analysis of our study is of interest to investors at an institutional level who aim at detecting the risk associated with the clean energy market through proper financial modeling. Besides, this study opens up a new domain to sustain financial as well as economic prospects by protecting the environment through clean energy stock as the investment in clean energy stocks results in producing a substantial effect on the economy and the environment as well.

Keywords Clean energy · Gold · Coal · Environment · Sustainability

Introduction

To manage the climate changes as well as for the attainment of sustainable development goals, countries have emphasized promoting the usage of energies to lift the stability of economic and financial aspects by setting a program to stimulate, direct, create, and promote the development of the clean energy sector (Gao et al. 2020). Subsequently, both developed as well as developing countries are facing the pressure instigated by the change in the climate along with increased consumption of energy. This required to focus on accelerating the processes with respect to low emission of pollutants and decarbonization (Ahuja and Tatsutani 2009). According to the World Nuclear Association (2020), the utilization of energy

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might help in eradicating the concern of CO_2 emission whereas the utilization of fossil fuels contributes to causing global warming. Therefore, the users of traditional energy are seeing the alternatives of utilizing clean energy in the form of solar, wind, and hydropower (Zhao 2020). Furthermore, clean energy has a strong substitution influence on traditional fossil fuels particularly oil (Lv et al. 2019).

When viewing environmental changes, economic activity and resource utilization play a vital role. For instance, a study conducted in China demonstrates that natural resources (NRs) and financial development result in an improved ecological footprint in China (Zia et al. 2021). NR and human capital negatively influence CO_2 emission in the long run and are positively associated with carbon emission. However, economic growth (EG) and human capital are positively associated with carbon emission, whereas NRs have a negative influence on carbon emission. Additionally, EG and human capital are positively, while natural resources are negatively, associated with an ecological footprint, in both the long and short run (Zhang et al. 2021). A study was conducted in Turkey to determine the long-term and causal association among economic progress, CO_2 emissions, energy consumption, and employment ratio. It employed the autoregressive distributed lag bounds analysis technique of cointegration. The findings of the study indicated that policies on energy reservation such as controlling CO_2 emissions and regulating energy consumption cannot have a negative influence on the output growth of the country (Ozturk and Acaravci 2010).

The component of energy has been the prime feature for the economic development of a country (Ferdaus et al. 2020) along with having a long-term impact on the environment as well (Mahmood et al. 2020). A study conducted by Khan et al. (2021) examined the relationship between economic, health, and environmental elements with green energy consumption, and maintained that the use of fossil fuel adversely affects the environmental quality and reduces the risks of diseases linked with undernourishment and respiratory system and hence results in increased death ratio. The use of energy is regarded as a facet that contributes to degrading the environment (Gupta and Dalei 2020). However, Murshed et al. (2020) shared a sight that the utilization of renewable energy can substantially help in mitigating the detrimental effect on the environment as well as play a role in sustainability. Like any other commodity, energy is not free of cost; in the parallel vein, fluctuation in prices of energy tends to have a major impact on the consumption of energy (Murshed and Tanha 2020; Thomas and Rosenow 2020), while having an indirect effect on EG (Hussain et al. 2020; Mukhamediyev and Spankulova 2020). While energy price increase might eventually lead towards affecting sustainability, it can contribute and perhaps give a solution to environmental problems (Al-Mulali and Ozturk 2016).

Besides, prices of energy demonstrate a prime role not only in economic but also in environmental development aspects. The research conducted by Ozturk (2016) inspects the association between biofuel consumption and production of multiple predictors of environmental and socio-economic sustainability by utilizing the functional form of the Solow growth model. The findings reveal that growth elements have a significant association with biofuel consumption whereas environmental indicators increase with the growing usage of biofuel. A key statistical tool employed to assess the causal nexus and cointegration among EG and CO_2 emissions is the environmental Kuznets curve (EKC). Studies in energy and environmental economies commonly use EKC. Koondhar et al. (2021) suggested that future studies be conducted on EKC with sustainable technology science. A study conducted in Bangladesh by Anser et al. (2021) revealed that the pollution level in the country is adding to the carbon emissions and destroying the environment in terms of non-renewable energy and globalization index. However, the growth levels (GDPs) and the square of GDP approves the EKC hypothesis in the region. The study proved the relationship between the growth in GDP and the level of carbon emission by establishing a bidirectional association between EG and energy usage.

Ju et al. (2017) found that the prices of energy have an unfavorable influence on EG whereas distortion has also been observed with respect to the environment. This means that along with economic growth, environmental concerns are outweighing the attention (Panwar et al. 2011), which emerges the need of incorporating clean energy stock (CES) that differs from traditional stock to maintain sustainability. Particularly, CES includes the characteristics of both the conventional stock market and commodities related to energy. However, the CES and traditional stocks differ due to their operating mechanism as clean energy includes those corporations that are engaged in the production and supply of green energy and allied goods and services.

Clean energy is regarded as a dynamic and promising industry. Investment in the clean energy industry might help in promoting economic development via incorporating facts and figures with respect to each manufacturing subsector (Fuentes and Herrera 2020). According to Omer (2008) and Troster et al. (2020), energy investment has recently gained more importance over time because it is reliant on the profitability and the associated risk related to financial aspects of renewable energy companies and clean energy stock (CES). So, the dynamics of price linked with energy is now viewed as the foremost energy-associated risk factor which in turn affects the financial performance of project investment accompanying clean energy for the sustainability of energy resources (Kumar et al. 2012; Saeed et al. 2020). Investors predominantly focusing on clean energy stock leaves less room for speculation in the market as they are more informative (Shahzad et al. 2020). Further, organizations that engage in green financing have a better image in the investor's mind because of having a green status.

Regarding the energy perspective, there are a diverse set of energies explained in the literature including oil, electricity, gas, and coal. According to Sadorsky (2012) and ÓhAiseadha et al. (2020), as the concerns for climate changes increase, the security of energy sectors increases in which oil, gas, and coal are viewed as key components. However, viewing the energies, coal has gained more prominence in the literature due to having its strong relation in causing environmental degradation in the form of CO_2 emission and other air pollutants (Zhao and Luo 2018). Contrary to this, Sun et al. (2019) and Gu et al. (2020) found a link between coal prices (CP) and CES. Despite the fact, still, this area is understudied in the available literature regarding how coal might influence CES despite being the contributor towards CO_2 emission. Therefore, keeping in view the abovementioned quarrel, this study considers coal its first variable to examine its link with CES.

The presence of uncertainties in the oil market, for instance, an unexpected boost in the oil prices (OP), forces the need for substitution of energy that perhaps accelerate the transition in utilization of energy (Zhao 2020). Consequently, fluctuations in oil prices are an imperative component that forces clean energy development though there is no agreement concerning the nexus between OP and CES among the economists. In line with this argument, it is necessary to shed light on the connection of oil price with CES price to further broaden the horizon from the perspective of sustainability.

Similarly, in developed economies, investment in gold and oil provides an opportunity towards hedging against the stock market (Chkili 2016; Khalfaoui et al. 2015). Reserves, as well as the prices of gold, play a domineering part in generating economic activity which results in helping towards income generation that eventually contributes positively to the attainment of environmental and sustainability goals (Niesenbaum 2020). Also, in the extant literature, the researchers assessed the nexus between gold prices (GPs) and stock prices (Harahap et al. 2020; He et al. 2020; Mukherjee and Bardhan 2020). However, the pieces of evidence related to gold and CES are limited in the literature; thus, this study sightsees the link between gold and CES to explain whether gold prices contribute towards clean energy stock positively or negatively.

Moreover, while considering natural gas from the perspective of its effect on the environment, Linn and Muehlenbachs (2018) highlighted that natural gas prices result in benefiting the environment via the reduction of harmful gases. In the parallel vein, natural gas prices also affect the financial market in terms of stock prices. Consequently, Hoque et al. (2020) accentuated that higher prices related to oil and natural gas fall out in causing cost-push inflation which results in having a negative influence on the financial markets, especially the stock prices. Correspondingly, in the literature, researchers examined the natural gas prices (NGPs) with emissions, market structure, investment, and stock prices (Ahmed 2018; Brehm 2019; Holladay and LaRiviere 2017; Knittel et al. 2015). However, to date, not much is known about how the volatility in NGP affects clean energy stock prices. Therefore, natural gas inclusion in our study is imperative from the point of sustainability as utilization of natural gas results in generating a lesser amount of CO_2 as compared to coal and oil (Gong 2020; You et al. 2020). Secondly, natural gas is regarded as one of the foremost commodities in the energy sector not only because this component supplies 22% across the world for the usage of energy (International Energy Agency 2015); along with this, it also contributes to the stock market. So, natural gas is beneficial for the environment and stock prices which primarily makes it the prime source of energy.

Based on the gap found in the extant literature, this study is significantly contributing in numerous ways. Firstly, though shreds of evidence are available concerning the interaction of coal, natural gas, and gold prices with stock prices, however, limited work has been conducted from the coal, natural gas, and gold prices' perspective of CES. Thus, this study provides evidence regarding the link between the aforementioned variables and CES. Secondly, this study adds to the literature, by employing the ARDL technique to evaluate the link between the specified variables. According to the best of researchers' knowledge, this novel technique has not been utilized earlier to explore the nexus between the said variables in one study. Therefore, the current study provides a new perspective by considering the influence of energy prices from the viewpoint of oil, natural gas, and coal along with the precious metal, i.e., gold prices, on CES.

Besides, the subsequent article is schematized as specified: part 2 specifies the interconnected literature related to variables, part 3 stipulates an inclusive description of the methodology employed for the research, and part 4 divulges the results and discussion linked to the findings as well as extant literature. In the end, part 5 illustrates the conclusion along with deliberate recommendations.

Literature review

Regarding climate changes, the conventional energy system plays a prime role in contributing to the detrimental effects on the environment. All sources of energy have a substantial effect on the environment. Based on the sustainable development goals (SDGs), research by Gyamfi et al. (2021) attempted to emphasize the need for ecological-economic development, consumption of clean energy, and climate change mitigation. The study established that in the E7 economies, energy received from sources of fossil fuel results in emissions of CO_2. The improvement in energy efficiency results in cost savings and reduction of CO_2 emissions. It also helps reduce the nation's dependence on energy supplies from other countries. The same notion has been endorsed by Ozturk (2013), mentioning that when energy sources are available uninterruptedly at reasonable prices, it can benefit from enhanced energy efficiency ultimately resulting in reduced reliance on foreign fossil fuels.

According to the statistics, energy sources including coal, gas, and oil accounts for 60% of the global CO_2 emission affecting the environment in 2013 (Alam et al. 2020). Viewing the global energy consumption, coal consumption institute about 27% whereas natural gas consumption rose to 24.2% as per a report of British Petroleum (2016). Viewing the environmental protection concerns, the significance of clean energy has gained momentum in order to secure energy for future generations, and to attain this objective firms are also focusing on increasing the investments in green energy markets (Yong et al. 2019). As per the estimation of the Energy Information Administration (EIA 2018), until 2040, renewable energy portion in the total energy will be 18%; however, this portion is less than the threshold of 28%, as this percentage of energy is crucial for eradicating the detrimental effect on the atmosphere; thus, investment in modern energy has gained more importance nowadays due to the sustainability apprehensions.

Recognition of the global importance of clean energy stock as an alternate choice to traditional stock has been driven by several aspects such as changes in the climate, scarcity of fossil fuel, volatile OP, and innovation in clean energy technology (Naeem et al. 2020). Shahzad et al. (2020) examined the market efficiency and found higher efficiency in the case of CES and European markets when the market has an upward trend, whereas in the case of the USA, upward trend is seen when the market is less efficient. Investors during the crisis period pay more attention to safe assets (e.g., oil and gold) and dispose of risky holdings to preserve sustainability. Besides, Ferrer et al. (2018) have asserted that the increase in prices of oil perhaps leads towards increasing the efficiency of the stock market related to clean energy stockholding companies.

Ahmad (2017) evaluated the link of OP with technology and CES and found OP as a profitable hedge when it is harmonized with the technology and CES. On the adjacent side, Kumar et al. (2012) also found a positive link between OP and CES prices. In contrast, when the oil prices upsurge, it results in affecting the stock prices as well as economic activity negatively (Kilian 2009). Uncertainty in OP affects the CES market (Dutta 2017). Pham (2019) also demonstrated a heterogeneous relationship between oil prices and clean energy stock; for instance, energy management and biofuel stocks are linked to the OP whereas wind, fuel cell, and geothermal stocks are the least associated with the oil prices. Shreds of evidence related to OP and CES prices are displayed in Table 1.

Coal is the prime resource used by the economy as it is abundant than gas and oil and hence it is likewise that globally the utilization of coal as an energy increases and reaches its peak; however, in the long term, it starts to decline (Chakravorty et al. 2003). So, the utilization of costly solar energy can be done in the case where the ceiling is binding, and returns back to the usage of coal as it is viewed as a principal energy source. Lin and Chen (2019) revealed that there is international pressure on China for the sustainable development of climate, energy, and the environment; hence, China is striving to reduce the utilization of coal. Further, they found that coal is also viewed as non-clean energy because when the prices of coal increase, then firms need fewer allowances related to the CO_2 emission. However, from the viewpoint of the new energy stock market, it is more sensitive against the variation in the coal prices (CP) in the course of the development of technologies related to new energy and the decline in the cost of usage of new energy. So a stable environment related to investment might be fruitful for the investors of stocks with respect to new energy.

Concerning China, Xie et al. (2015) tried to identify the sort of energy that is mainly responsible for the low energy efficiency. They identified that there is no apparent improvement in the overall efficiency of clean energy, whereas moderate improvement in the coal energy efficiency has been observed. However, even a moderate improvement in coal energy adds most to the whole inefficiency related to energy as it is the principal source of fuel that is being utilized in China. The outcomes of the study conducted by Jiang et al. (2020) revealed a higher level of cohesiveness among CP, trading of carbon emission, and the new energy stock. Besides, Reboredo and Ugolini (2018) found that energy prices including coal demonstrate a substantial impact on clean energy stock.

Gas prices also affect the stock market because oil, natural gas, and coal are the most important resources of energy in the world particularly when assessing the gas prices; it seems to have a substantial impact on growth which as a result affects the stock returns as well (Acaravci and Kandir 2012). Kanamura (2020) disclosed that a positive link of NGP with energy stock prices exists while the price of natural gas has a growing function towards the energy prices. Ramos and Veiga (2011) found that as the gas prices increase, it fall outs in having a positive effect on stock returns with a small coefficient. On the adjacent side, Sun et al. (2019) found a weak effect of natural gas prices on new CES prices.

On the adjacent side. Concerning Turkey, Ordu and Soytaş (2016) shared an opposing view related to gas price. They identified that the integration of their financial market is sluggish because NGPs are not substantially associated with the index of the market. This also shows that the dependency on commodities might be the driver that built the link between the prices of assets and the commodity. Consistently,

Table 1 Association between oil prices and clean energy stock

Positive relationship	Negative relationship	Weak relationship
(Managi and Okimoto 2013)	(Kocaarslan and Soytas 2019)	(Nasreen et al. 2020)
(Zhang et al. 2020)		
(Lv et al. 2019)		
(Reboredo et al. 2017)		

Oberndorfer (2009) elucidated in his study that energy prices such as prices of oil and coal affect the returns related to stock on one end, yet natural gas does not affect the returns. Besides, concerning India, Kumar et al. (2019) analyzed the link between NGP and stock prices. Results divulged that no cointegration exists between natural gas and stock prices.

Gold is seen as one of the common commodities that are having effective hedging against the adversative movement in return related to the stock market (Elie et al. 2019). Gold is principally considered a safe property during a stressful time (Ciner et al. 2013). Accordingly, gold is recognized globally as a protector during the crisis time which in turn serves economic purposes such as investment in land and stocks (Abraham and Ramanathan 2020). Additionally, this is the main causal factor that gold is considered an asset that is tangible, indestructible, and storable that is why banks hold reserves of gold as part of their resources (Jaiswal and Manoj 2015).

In the same vein, the stock markets are also affected by numerous economic aspects such as gold prices (Raza et al. 2016). Furthermore, as per the results of Hillier et al.'s (2006) study, there exists a weak link between precious metals including gold with stock market indices. Arouri et al. (2015) elucidated in their study that gold prices play a substantial role in affecting the stock prices which in turn leads to better risk-adjusted returns; therefore, gold has proved to be a safe-haven asset during a crisis. In the parallel shred of evidence, Baur and McDermott (2010) also specify that during a financial crisis, investment in gold is viewed as an alternative way to protect themselves. Additionally, there is meaningful volatility that exists among gold and the stock market; thus, gold, as well as stock together, is regarded as a crucial strategy to deal with financial crisis (Morema and Bonga-Bonga 2020).

On the adjacent side, Elie et al. (2019) found that gold is no longer a good safe-haven asset for CES. Moreover, pieces of evidence related to gold prices and stock prices are explicated by researchers like Ali et al. (2020), Baur and Lucey (2010), and Raza et al. (2016). Tursoy and Faisal (2018) revealed a negative influence of GPs on stock prices, whereas Gilmore et al. (2009) unveiled a unidirectional link between GP and stock prices. Further, Syahri and Robiyanto (2020) also divulged the significant effect of GP on stock prices. So, investors react differently in terms of showing positive or negative behavior towards gold prices during the financial crisis (Sheikh et al. 2020).

The results of a study maintained that prices of gold are positively associated with prices of oil and with financial risk, while negatively linked to conventional and Islamic stocks. However, the direction of the nexus is similar with both types of securities. Besides, the direction of the relationship is similar for conventional and Islamic stocks, but the strength varies particularly in the case of oil and financial risk (Godil et al. 2019). Moreover, concerning sustainability, the clean stock is gaining more prominence among the investors in which gold is regarded as an important asset that might help in attaining the goals of sustainability. As Ahmad et al. (2018) elucidated in their study that gold is not the best hedge related to CES, yet if it is employed towards hedging, the risk associated with clean energy stock price then VIX is an effective and better hedge as compared to gold for clean energy stock prices.

Research methodology

In the present study, daily data were used from 2-22-2011 to 2-14-2020 for analysis. The detail of each variable is specified in Table 2. Data for variables like coal prices and natural gas prices are taken from investing.com while gold prices are extracted from World Gold Council, and OPs are downloaded from Federal Reserve Economic Data. The data related to the clean energy stock index is taken from the website of Standard and Poor (S&P).

Built on the aforementioned literature, the subsequent variables are designated to assess the influence of GPs, OPs, coal prices, and NGPs on CES from 2011 to 2020 using daily data. The regression equation is mentioned below for time series data. Furthermore, in the stated equation, CES indicates clean energy stock while GP, CP, OP, and NGP indicate the gold prices, coal prices, OPs, and NGPs respectively. In the itemized equation, the constant term is denoted by β_0 while coefficients of the independent variables are symbolized by β_1 to β_4.

$$\mathrm{CES}_t = \beta_0 + \beta_1 GP_t + \beta_2 OP_t + \beta_3 CP_t + \beta_4 NGP_t + \epsilon_t$$

Cointegration test

To assess the cointegration, a bound test is employed. A value of F statistics at a 5% significance level is utilized in deciding

Table 2 Description of variables

Variable name	Data source	Measurement unit
Gold prices	World Gold Council	USD/per troy ounce
Clean energy stock	S&P website	S&P Global Clean Energy Index
Crude oil prices	Federal Reserve Economic Data	Dollars per barrel
Coal prices	Investing.com	Coal future (UCXMc1)
Natural gas prices	Investing.com	USD/Mmbtu

the long-run nexus between the variables. If the computed value of F statistics is greater than the upper value of bound, then cointegration exists. On the other side, if the F statistics value is less than the lower bound value, it depicts no long-run nexus, whereas it is undecidable when the F value lies between the upper and lower values of the bounds. To examine the long-run association, the subsequent hypotheses are anticipated for assessment.

$$H_0 : \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = 0$$
$$H_1 : \varphi_1 \neq \varphi_2 \neq \varphi_3 \neq \varphi_4 \neq \varphi_5 \neq 0$$

The following is the equation for bounds testing to ascertain the cointegration as well as the long-run and short-run nexus grounded on the abovementioned two hypotheses among the variables of the study.

$$\Delta \mathrm{CES}_t = \varphi_0 + \varphi_1 \mathrm{CES}_{t-1} + \varphi_2 \mathrm{GP}_{t-1} + \varphi_3 \mathrm{OP}_{t-1} + \varphi_4 \mathrm{CP}_{t-1} + \varphi_5 \mathrm{NGP}_{t-1} + \sum_{i=1}^{q} \beta_1 \Delta \mathrm{CES}_{t-1} + \sum_{i=1}^{q} \beta_2 \Delta \mathrm{GP}_{t-1} + \sum_{i=1}^{q} \beta_3 \Delta \mathrm{OP}_{t-1} + \sum_{i=1}^{q} \beta_4 \Delta \mathrm{CP}_{t-1} + \sum_{i=1}^{q} \beta_3 \Delta \mathrm{NGP}_{t-1} + \epsilon_t$$

The abovementioned equation Δ with CES shows the change operators. SIC is utilized for choosing the optimal lag which is indicated by $t - 1$. φ_1 *to* $\varphi_5$and β_1 *to* β_5 are the elements that will be assessed. Therefore, if a long-run nexus is present among the variables of the study, then we will examine the dynamic ARDL simulations model to inspect the short- and long-run model.

Dynamic ARDL simulations

To inspect the short-run as well as the long-run nexus among the variables, Jordan and Philips (2018) projected a model for time series data named dynamic ARDL simulations that have the capabilities to assess and stimulate along with automatically plotting the graphs related to the actual positive as well as a negative variation in the independent variables together with its impact on the dependent variable by keeping the other variables constant in the specified equation. This approach is used as it provides relative assessment related to the study variables in terms of long- as well as short-run association; along with that, it also helps in removing the shortcomings that appeared when using the traditional ARDL technique. Furthermore, taking other independent variables constantly helps to assess and stimulate as well as predict graphs by specifying the positive shocks and negative shocks in the independent variables (Jordan and Philips 2018; Sarkodie and Strezov 2019). Besides, before applying this model, all variables need to have a cointegration association. In our study, we have applied 5000 simulations for the vector of parameters by employing the multivariate normal distribution for the novel ARDL model as proposed by Jordan and Philips (2018). The equation is demonstrated below:

$$\Delta \mathrm{CES}_t = \delta_0 \mathrm{CES}_{t-1} + \beta_1 \mathrm{GP}_t + \delta_1 \Delta \mathrm{GP}_{t-1} + \beta_2 \mathrm{OP}_t + \delta_2 \Delta \mathrm{OP}_{t-1} + \beta_3 \mathrm{CP}_t + \delta_3 \Delta \mathrm{CP}_{t-1} + \beta_4 \mathrm{NGP}_t + \delta_4 \Delta \mathrm{NGP}_{t-1} + \varphi \mathrm{ECT}_{t-1} + \varepsilon_t$$

The dynamic ARDL simulations model is shown in the above equation in which β is used to represent the long-run coefficients while δ displays the short-run coefficients. To inspect the adjustment speed from the disequilibrium, the error correction term is represented by ECT.

Results and discussion

Table 3 postulates the descriptive statistics related to the study variables. The outcomes related to a minimum, mean, and maximum values are as follows: CES (392.63–633.38–1202.59), CP (33.30–56.88–79.75), NGP (1.639–3.140–6.149), GP (3.020–3.130–.277), OP (26.19–71.208–113.39).

To analyze the stationarity of data is one of the imperative norms for time series data. Table 4 in this study is assessed to highlight the stationarity of variables through Augmented Dickey-Fuller (ADF) as well as Phillip-Perron (PP). The outcomes show that the scrutinized series is stationary at the first difference. Therefore, the fallouts allow the ARDL technique to be executed.

Table 3 Descriptive statistics

Variables	Observations	Mean	Std. Dev	Min	Max
Clean energy stocks	2331	633.3873	147.0158	392.6300	1202.590
Coal prices	2331	56.88631	11.11987	33.30000	79.75000
Natural gas prices	2331	3.140955	0.740272	1.639000	6.149000
Log gold prices	2331	3.130358	0.055964	3.020941	3.277609
Oil prices	2331	71.20813	22.93890	26.19000	113.3900

The results of the Akaike information criterion (AIC), Schwarz information criterion (SC), and Hannan-Quinn information (HQ), LogL, Final Prediction Error (FPE), Sequentially Modified Likelihood Ratio (LR), and criterion are displayed in Table 5. As per the outcome of HQ and SC, lag 1 is appropriate, yet on the other side, the AIC shows that lag 2 is more suitable. So here the researchers have used the SC that specifies the suitability of lag one for the model.

Table 4 Unit root tests

Unit root test table (PP)						
At level						
With constant		Clean stock	Coal prices	Natural gas prices	Log gold	Oil prices
	t-Statistic	−2.2961	−1.2583	−2.5817	−1.5880	−1.4280
	Prob.	***0.1734***	***0.6509***	***0.0969***	***0.4886***	***0.5699***
		n0	n0	*	n0	n0
With constant and trend	*t*-Statistic	−1.9455	−1.4194	−3.0873	−1.4175	−1.9575
	Prob.	***0.6300***	***0.8554***	***0.1095***	***0.8560***	***0.6236***
		n0	n0	n0	n0	n0
Without constant and trend	*t*-Statistic	−1.1400	−1.2274	−1.1064	0.2290	−1.1537
	Prob.	***0.2321***	***0.2021***	***0.2442***	***0.7527***	***0.2272***
		n0	n0	n0	n0	n0
At first difference						
		d (clean stock)	d (coal prices)	d (natural gas prices)	d (log gold)	d (oil prices)
With constant	*t*-Statistic	−41.5090	−45.1905	−51.8683	−48.7488	−50.9351
	Prob.	***0.0000***	***0.0001***	***0.0001***	***0.0001***	***0.0001***
		***	***	***	***	***
With constant and trend	*t*-Statistic	−41.6005	−45.1373	−51.8582	−48.7502	−50.9255
	Prob.	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
		***	***	***	***	***
Without constant and trend	*t*-Statistic	−41.4620	−45.1818	−51.8671	−48.7582	−50.9279
	Prob.	***0.0000***	***0.0001***	***0.0001***	***0.0001***	***0.0001***
		***	***	***	***	***
Unit root test table (ADF)						
At level						
With constant		Clean Stock	Coal Prices	Natural Gas Prices	Log Gold	Oil Prices
	t-Statistic	−2.4989	−1.2698	−2.6405	−1.6184	−1.4760
	Prob.	***0.1158***	***0.6457***	***0.0850***	***0.4730***	***0.5459***
		n0	n0	*	n0	n0
With constant and trend	*t*-Statistic	−2.1069	−1.4384	−3.1100	−1.4579	−1.8990
	Prob.	***0.5411***	***0.8496***	***0.1041***	***0.8435***	***0.6547***
		n0	n0	n0	n0	n0
Without constant and trend	*t*-Statistic	−1.2785	−1.1871	−1.1230	0.2223	−1.2208
	Prob.	***0.1857***	***0.2156***	***0.2382***	***0.7508***	***0.2042***
		n0	n0	n0	n0	n0
At first difference						
		d (clean stock)	d (coal prices)	d (natural gas prices)	d (log gold)	d (oil prices)
With constant	*t*-Statistic	−28.2250	−30.6760	−51.5590	−48.7361	−50.8640
	Prob.	***0.0000***	***0.0000***	***0.0001***	***0.0001***	***0.0001***
		***	***	***	***	***
With constant and trend	*t*-Statistic	−28.2804	−30.6739	−51.5486	−48.7369	−50.8539
	Prob.	***0.0000***	***0.0000***	***0.0000***	***0.0000***	***0.0000***
		***	***	***	***	***
Without constant and trend	*t*-Statistic	−28.2184	−30.6615	−51.5642	−48.7453	−50.8615
	Prob.	***0.0000***	***0.0000***	***0.0001***	***0.0001***	***0.0001***
		***	***	***	***	***

Table 5 VAR lag order selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−9790.343	NA	0.003187	8.440623	8.453009	8.445137
1	12372.25	44210.60	1.65e−11	−10.63528	−10.56097*	−10.60820*
2	12405.55	66.29951*	1.64e−11*	−10.64244*	−10.50619	−10.59279

While scrutinizing the long-run nexus of the variable mentioned in the study; the bounds test is employed. The outcomes obtained through the execution of the bounds test are indicated in Table 6. Based on the results at a 5% significance level, a long-run relationship exists as the measured value of F statistics is greater than the upper bound.

Table 7 indicates the dynamic ARDL simulation results. ECT posits the error correction term and it has a significant value of −0.3742, so as the specified value is between 0 and −1, it can be deduced that the adjustment in equilibrium shock is completed in a year for clean energy stock. Now, the influence of each factor on clean energy stock is discussed one by one, firstly if we look at GPs. In the long as well as the short run, GPs have a positive and substantial influence on CES. Thus, a 1% upsurge in gold prices boosts clean energy stocks by 0.8435% in the long run, whereas in the short run it boosts by 0.3820%. The result is in harmony with the study of Syahri and Robiyanto (2020) and Godil et al. (2020). This means that gold is regarded as a safe asset to attain sustainability. However, Elie et al. (2019) considered gold as a weak safe-haven asset, whereas Ahmad et al. (2018) elucidated that VIX is better than gold as far as hedge related to CES is concerned.

Moreover, while examining the link between OPs and CES, a substantial and positive effect on CES was found in the long as well as the short run. The results indicate that a 1% boost in OPs results in increasing the prices of clean energy stocks by 0.4570% in the long run while in the short run, a 1% increase in the prices of oil increases the demand for clean energy stock by 0.3350%. Henceforth, as the oil prices upsurge, it fall outs in encouraging the economic agents to use clean energy which in turn improves the CES prices. Therefore, outcomes are in harmony with the studies of (Lv et al. 2019; Reboredo et al. 2017; Zhang et al. 2020).

Table 6 ARDL bounds test

Test statistic	Value	k
F-statistic	4.445747	4
Critical value bounds		
Significance	I0 Bound	I1 Bound
10%	3.03	4.06
5%	3.47	4.57
2.5%	3.89	5.07
1%	4.4	5.72

Also, we explored the link between NGPs and CES in our study. The results illustrate a negative and substantial effect of NGPs on CES in the long as well as short run. The analysis of data specifies that a 1% upsurge in natural gas prices results in decreasing the clean energy stocks by 0.3929% in the long run and 0.2386% in the short run. This means that as the price of gas increases, it causes a decrease in clean energy stocks. The findings are consistent with Reboredo and Ugolini (2018). They revealed a negative influence of gas in the case of extreme downturn fluctuation on CES. However, the findings are not consistent with the results of several researchers, i.e., Oberndorfer (2009); as the researcher indicated that NGP does not affect stock returns, Ramos and Veiga (2011) found that gas prices are having a positive impact on the stock, and Sun et al. (2019), as they specify a weak effect of GPs on new energy (clean) stock prices.

Lastly, the link between coal prices and CES is examined. The results revealed that coal prices have a positive as well as significant effect on CES; therefore, as the prices of coal increase by 1%, it causes an increase in clean energy stocks by 0.3194% in the long run while a 0.4800% increase in the short run. The results are in line with the study of Reboredo and

Table 7 Dynamic ARDL simulation model results

Variables	**Coef.**	**Std. err.**	***t***	***P>t***
Error correction term (ECT)	−0.3742	0.1383	−2.7065	0.0034
Gold prices	0.8435	0.4287	1.9673	0.0493
$\Delta \text{Goldprices}_{t-1}$	0.3820	0.1479	2.5828	0.0099
Oil prices	0.4570	0.1442	3.1698	0.0016
$\Delta \text{Oilprices}_{t-1}$	0.3350	0.1436	2.3325	0.0198
Natural gas prices	−0.3929	0.1537	−2.5560	0.0053
$\Delta \text{Naturalgasprices}_{t-1}$	−0.2386	0.1303	−1.8312	0.0336
Coal prices	0.3194	0.0937	3.4107	0.0007
$\Delta \text{Coalprices}_{t-1}$	0.4800	0.2367	2.0276	0.0427
_cons	7.0595	1.9676	3.5879	0.0003
R-square			0.7069	
Observations			2331	
Simulations			5000	
$F(9, 1846) = 2.47$			Prob > F = 0.0085	

t statistics in parentheses $^{***}p < 0.1$; $^{**}p < 0.01$; $^{*}p < 0.05$

Variable without t−1 are long-run, whereas with t−1 depicts the short-run results for each variable

Table 8 Diagnostic tests

Diagnostic statistics tests	X^2 (*P* values)	Results
Breusch-Pagan-Godfrey ARCH	0.9694 0.5976	No issue of heteroscedasticity
Breusch-Godfrey Serial Correlation LM Test	0.2440	No issue of serial correlations.
Ramsey RESET Test	0.9801	The model is specified appropriately.
Jarque-Bera	0.1584	The estimated residuals are normal.

Ugolini (2018). They found a positive influence in the case of upward price fluctuation. Besides, Sun et al. (2019) found that fossil energy prices, which include coal, contribute a small proportion to the price fluctuations of new energy organizations. Further, Gu et al. (2020) revealed the presence of a substantial bi-directional association between the CP and the CES, whereas Jiang et al. (2020) found the link between CP and CES at high quantiles.

The fallouts of the different diagnostic statistics are indicated in Table 8. To investigate whether the estimated ARDL model is specified properly or not, a Ramsey reset test was used. The fallouts of the Ramsey reset test specify that the estimated model of ARDL is correctly specified in the current study. While assessing the serial correlation issue in the employed model, Breusch-Godfrey Serial test was used. Results specify that no serial correlation issue is present in our estimated model. To examine the heteroscedasticity problem in the estimated model, Breusch Pagan Godfrey test and ARCH test were applied which indicate that no problem related to heteroscedasticity exists in our model, whereas the analysis Jarque-Bera reveals the normality of residuals related to the estimated model.

Dynamic ARDL simulation graphs

Subsequently, the graphs under this dynamic technique are utilized to demonstrate the real change observed in the independent variable along with its influence on the dependent variable. In this study, we have assessed the variation in the independent variable either positive or negative, and its influence on the dependent variable. The specified Figure 1 depicts the influence of coal prices on the CES. It indicates a positive and negative 10% change in coal prices and its impact on the clean energy index; thus, the first graph indicates that a 10% increase in coal prices has a negative influence on the CES in the short run; however, it turns out to be positive in the long run, while 10% decrease in coal prices has a negative influence on CES in the short run which again turns out to be positive later.

The itemized Figure 2 portrays the influence of natural gas prices on the clean energy index. It designates a positive and negative 10% change in NGPs and its influence on the clean energy stock index; therefore, the first graph indicates that a 10% increase in NGPs has a negative influence on the CES in the short run; however, it turns

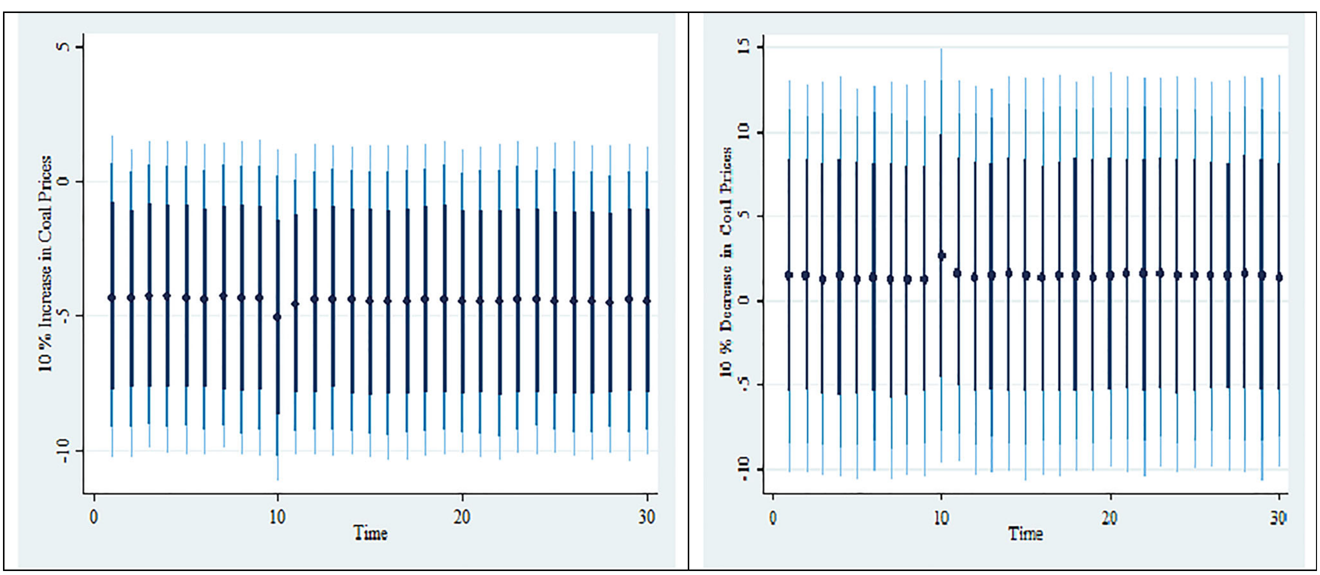

Fig. 1 Coal prices and Global CES Index. The above graphs specify ±10% in coal prices and their impact on the CES index. The dots demonstrate the mean prediction value whereas the dark blue to light blue lines specify 75%, 90%, and 95% confidence interval correspondingly

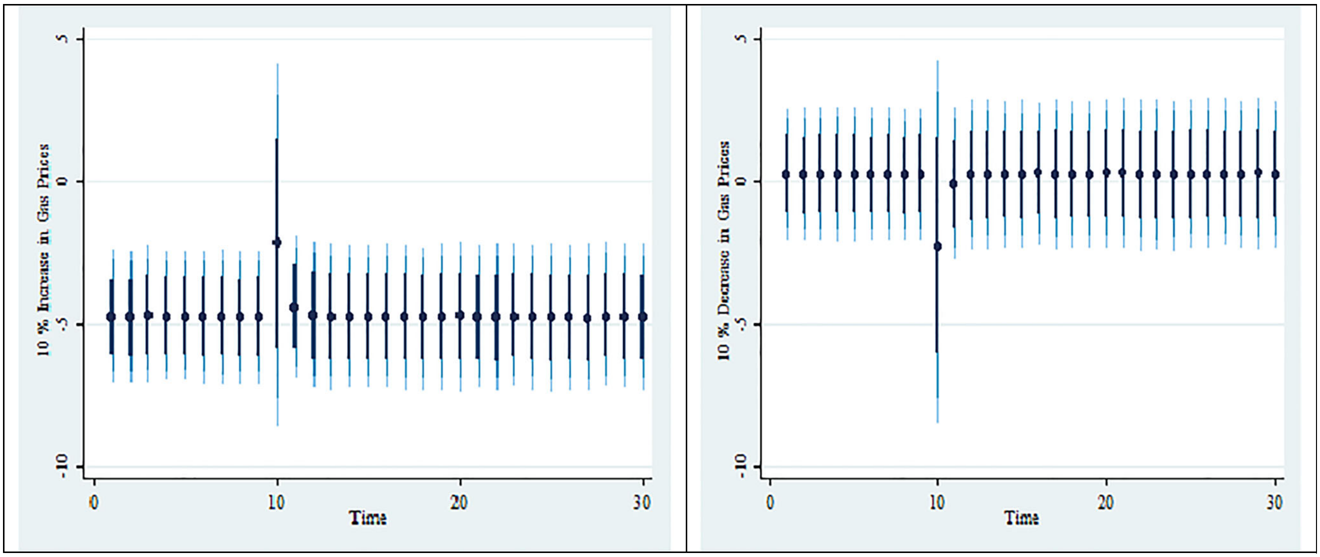

Fig. 2 Natural gas prices and Global Clean Energy Index. The above graphs specify ±10% in NGPs and their influence on the CES index. The dots demonstrate the mean prediction value whereas the dark blue to light blue lines specify 75%, 90%, and 95% confidence interval respectively.

out to be positive in the long run, while 10% decrease in NGPs has a negative influence on CES in the short run which again turns out to be positive later.

Figure 3 represents the influence of oil prices on the CES. It designates a positive and negative 10% change in OPs and its influence on the clean energy stock index; therefore, the left figure indicates that a 10% boost in OPs has a negative influence on the CES in the short run; however, it becomes positive in the long run. On the adjacent side, a 10% decrease in OPs has a negative influence on CES in the short run which again becomes positive at a later stage, i.e., in the long-run period.

Figure 4 represents the influence of gold prices on the clean energy index. It designates a positive and negative 10% change in gold prices and its influence on the clean energy index; therefore, the graph on the left indicates that in the short run, a 10% increase in GPs has a negative influence on the CES index; however, it becomes positive in the long run, while 10% decrease in gold prices has a negative influence on CES in the short run which again turns out to be positive in the later period, i.e., long run.

Conclusion and policy implications

To lift the stability of economic, financial, and environmental aspects, numerous countries have emphasized promoting the

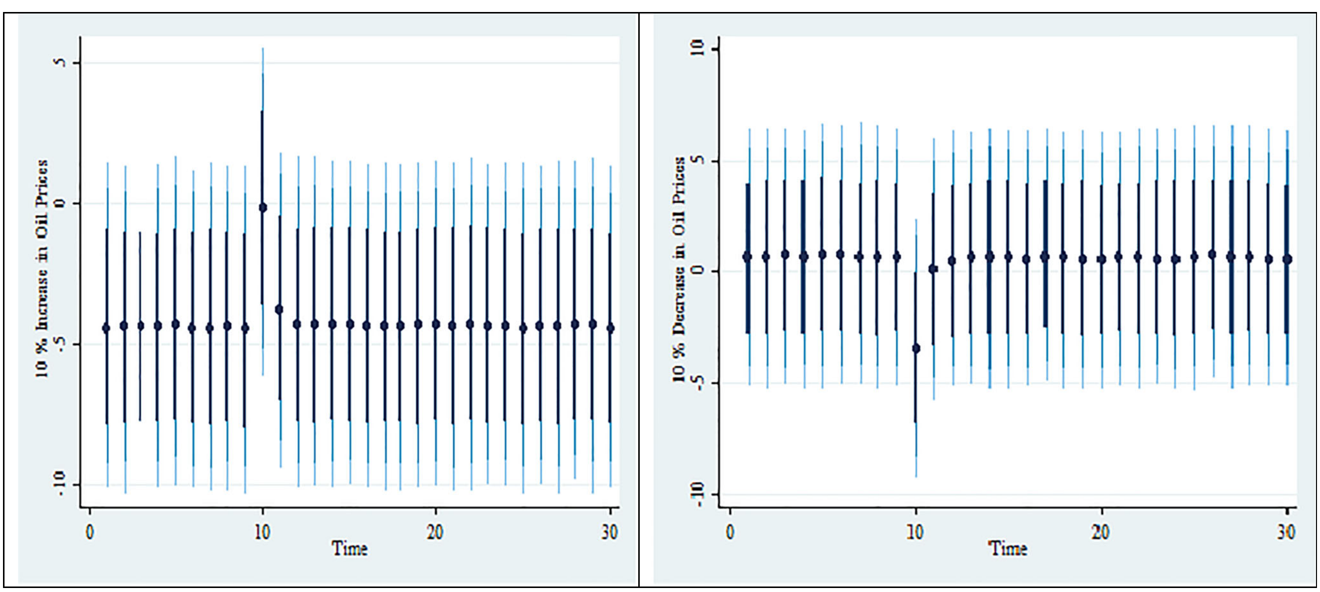

Fig. 3 Oil prices and Global Clean Energy Index. The above graphs specify ±10% in OPs and their influence on the CES. The dots demonstrate the mean prediction value whereas the dark blue to light blue lines specify 75%, 90%, and 95% confidence intervals

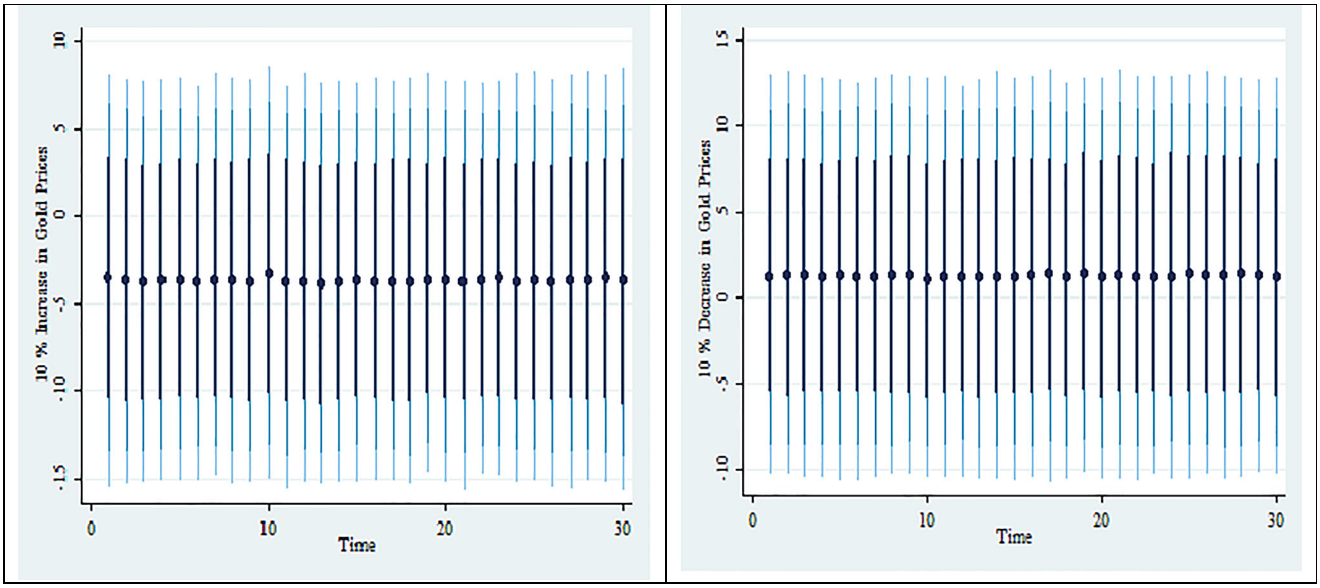

Fig. 4 Gold prices and Global Clean Energy Index The above graphs specify ±10% in GPs and their influence on the CES index. The dots demonstrate the mean prediction value whereas the dark blue to light blue lines specify 75%, 90%, and 95% confidence intervals

development of clean energy stock. In this study, the researchers have evaluated the impact of oil prices, coal prices, NGPs, and GPs on clean energy stock using the ARDL approach from the year 2011 to 2020. The result of daily data analysis specifies that in the long as well as the short run, gold prices and oil prices as well as coal prices have a positive and substantial effect on CES. On the other side, NGPs in the long as well as short run have a negative and substantial effect on CES. The empirical analysis of our study is of interest to investors at an institutional level aiming at identifying the risk associated with the CES market through proper financial modeling. Additionally, due to the increasing interest in substitute investments, the association between oil, coal, natural gas, gold, and clean energy stock markets is a crucial facet regarding decisions linked to investment as well as risk management. This study has opened up ground for future researchers in terms of examining the link between energy prices and CES in developed as well as developing countries to further expand the prospects via using ARDL and DCCE approaches.

Also, this study helps in understanding the link between energy prices and CES. Firstly, this will help the investors in understanding the risk associated with returns via proper allocation to a portfolio related to clean energy stocks. Secondly, this study will further help in identifying how the fluctuation in energy prices affects clean energy stocks. As investment in CES results in producing an imperative effect on the environment as well, therefore the findings of our study might help those investors who are interested in investing in firms that are ecofriendly. Thirdly, it is also worth noticing that investors are more prone to decarbonizing their portfolios to maintain sustainability by considering clean energy stock. Additionally, clean energy stocks are subtle towards variations in the long as well as short run in the business cycle which might perhaps imply a reduction in investments especially during low activity happening at the economic level. Therefore, swings in energy prices together with adding up the incentives for investors can help them to invest in the green economy. Fourth, proper incentives need to be provided to investors interested in green portfolios. This will play a substantial role to switch to clean energy stocks; otherwise, the investors perhaps will show reluctant behavior towards the greening of their portfolio which in turn hampers the migration to a low carbon economy.

Author contribution Munaza Bibi: original draft
Muhammad Kamran Khan: formal analysis
Sobia Shujaat: revision, writing draft
Danish Iqbal Godil: writing—original draft, conceptualization
Arshian Sharif: supervision
Muhammad Khalid Anser: supervision

Data availability The data of this manuscript was collected from different websites, i.e., World Gold Council, S&P, Federal Reserve Economic Data, and investing.com.

Declarations

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Consent for publication Not applicable

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