SELÇUK ÜNİVERSİTESİ
SOSYAL BİLİMLER MESLEK YÜKSEKOKULU DERGİSİ (e-ISSN: 2564-7458)
Cilt 27 • Sayı 2 • Kasım 2024
SS. 399-410 / Araştırma Makalesi

How Does Financial Development Affect the Volume of Nuclear Energy? Assessing The Relationship Between Nuclear Energy and Finance

Finansal Gelişme Nükleer Enerji Hacmini Nasıl Etkiler? Nükleer Enerji ve Finans Arasındaki İlişkinin Değerlendirilmesi

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ABSTRACT

The main objective of this study is to reveal the relationship between the volume of nuclear energy, which is becoming increasingly important as a clean energy source in today's world where the effects of environmental pollution are widely discussed, and financial indicators within the framework of nuclear energy producing countries. The study analyzes the relationship between the variables of domestic bank credit to the private sector (per capita) and gross capital formation (per capita) and the volume of nuclear energy per capita for the period 1970-2022. In the study, the panel cointegration test developed by Olayeni et al. (2020) was used to determine the long-run relationship between the variables. In addition, the coefficients were calculated using the cointegration estimator proposed by Bai (2009). According to the results of panel Fourier cointegration test, cointegration relationship is detected in all panel countries according to both PP and GLS values. According to the results of panel cointegration coefficient estimates, the CRD variable has a negative effect on the NUC variable, and the CAP variable has a positive and statistically significant effect. To the best of our knowledge, there is no study in the literature that examines the relationship between the per capita amount of bank loans to the private sector, the per capita amount of gross capital, and nuclear energy to understand the dynamics and impact of the financial and energy sectors on environmental and economic sustainability. It is thought that the study will make an important contribution to the related literature in this respect.

KEYWORDS

Nuclear Energy, Clean Energy, Environment, Finance, Co-integration

ÖZ

Bu çalışmanın temel amacı çevre kirliliğinin etkilerinin çokça konuşulduğu günümüzde temiz enerji kaynağı olarak önemi her geçen gün artan nükleer enerji hacmi ile finansal göstergeler arasındaki ilişkileri nükleer enerji üretimi yapan ülkeler kapsamında ele alarak ortaya koymaktır. Çalışmada 1970-2022 dönemi için Bankalar tarafından özel sektöre verilen yurtiçi kredi (kişi başına) ve Gayri safi sermaye oluşumu (kişi başına) değişkenleri ile Kişi başına nükleer enerji hacmi arasındaki ilişki ele alınmıştır. Çalışmada Olayeni et al. (2020) tarafından geliştirilen panel eşbütünleşme testi kullanılarak değişkenler arasındaki uzun dönemli ilişki tespit edilmiştir. Ayrıca Bai (2009) tarafından önerilen eşbütünleşme tahmincisi ile katsayılar hesaplanmıştır. Panel fourier eşbütünleşme testi sonuçlarına göre hem PP hem de GLS değerlerine göre tüm panel ülkelerinde eşbütünleşme ilişkisi tespit edilmiştir. Panel eşbütünleşme katsayı tahminlerinin sonuçlarına göre ise, CRD değişkeni NUC değişkeni üzerinde negatif ve CAP değişkeni pozitif ve istatistiksel olarak anlamlı etkiye sahiptir. Literatürde bildiğimiz kadarıyla finans ve enerji sektörlerinin ekolojik ve ekonomik sürdürülebilirlik üzerindeki dinamiklerini ve etkilerini anlamak açısından, bankaların özel sektöre kullandırdığı kredilerin kişi başına düşen miktarı, kişi başına düşen gayri safi sermaye miktarı ve nükleer enerji arasındaki ilişkilerin bir arada ele alındığı bir çalışma bulunmamaktadır. Çalışmanın bu yönüyle ilgili literatüre önemi bir katkı sağlayacağı düşünülmektedir.

ANAHTAR KELİMELER

Nükleer Enerji, Temiz Enerji, Çevre, Finans, Eşbütünleşme

Makale Geliş Tarihi / Submission Date 17.03.2024	*Makale Kabul Tarihi / Date of Acceptance* 06.06.2024
Atıf	Kazak, H. (2024). How Does Financial Development Affect the Volume of Nuclear Energy? Assessing The Relationship Between Nuclear Energy and Finance. *Selçuk Üniversitesi Sosyal Bilimler Meslek Yüksekokulu Dergisi*, 27 (2), 399-410.

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INTRODUCTION

In the 18th century, the Industrial Revolution, which was centered in England, started to have an impact on developing countries as of the first quarter of the 19th century, and with the differences in the use of energy resources (Aslan & Altinoz, 2021), there has been an increase in greenhouse gas emissions released into nature due to the speed of industrialization (Keleş, 2021). The increase in greenhouse gas emissions has had significant effects on climates and triggered global warming (Güler, 2018). As a natural consequence of the industrialization efforts of countries, attempts to reduce the amount of various greenhouse gases emitted into the atmosphere, which have negative effects on the ozone layer, and to cope with problems such as drought, drought, etc., especially climate change, have been put into practice with various international conventions such as the Montreal Protocol, Kyoto Protocol, and Paris Climate Agreement (Hassan et al., 2022).

Countries are trying to regulate their dependence on fossil fuels through appropriate energy policies to reduce greenhouse gas emissions into the atmosphere ((Lund, 2007; UNDESA, 2023). Energy security, sustainable energy supply, and economic sustainability all depend on reducing GHG emissions with the best possible financing and investment methods to preserve the natural balance (Wolde-Rufael & Menyah, 2010).

The development of sustainable energy strategies plays a major role in enhancing national energy security (*GET*, 2018). These tactics include protecting the environment and natural resources, increasing research and development to boost the production of clean energy and natural resources, producing clean energy, and allowing the financial sector to finance projects that reduce greenhouse gas emissions at reasonable prices (Owusu & Asumadu-Sarkodie, 2016; Gao & Chen, 2023).

To reduce the amount of greenhouse gasses emitted into the atmosphere, nations must commit to reducing the production and use of fossil fuels under international treaties (Santos et al., 2022). One of the important indicators is that the share of renewable energy sources in the total energy supply of OECD countries remains around 30% (OECD, 2024). The differences in energy supply and demand policies and energy sources due to the structural characteristics of countries, together with energy costs, make it easier to understand the underlying reasons for the inadequacy of OECD countries, which consider fossil fuels as safe harbors for 78% of their energy use capacity, in reducing the amount of greenhouse gasses emitted into the atmosphere (OECD, 2024).

In the context of sustaining production and consumption activities in the ecosystem in which we live, energy impacts economic growth and development. As a result, nations continue to value energy security, energy efficiency, and the economic supply of energy resources from nuclear energy and renewable clean energy sources together (Batool et al., 2023). It is not sustainable to meet energy needs solely from renewable clean energy sources because their production depends on environmental factors (Krūmiņš & Kļaviņš, 2023). When combined with renewable energy sources for long-term carbon-free energy production, nuclear energy is a competitive and viable energy source that can help decarbonize the energy sector (OECD and Nuclear Energy Agency, 2022)

Developed countries such as Germany and France, which prioritize long-term policies that reduce greenhouse gas emissions and clean energy production with reliable and affordable energy sources, energy efficiency and environmentally friendly electric vehicles away from energy import dependency, and greenhouse gas emission reduction (EPRS, 2020), and in this context, developed countries such as Germany and France, which put forward the will to transition to a low-carbon economy, pursue policies contrary to the international agreements they are a party to, with policies to replace nuclear power plants with low carbon emissions with coal and gas-fired power plants with high carbon emissions (OECD, 2024).

The challenging dimension of the high financing costs and long payback periods of nuclear energy investments that provide long-term low carbon emissions (Zimmermann & Keles, 2023) and the negative public perception of nuclear power plants due to past accidents and radioactive leaks are obstacles for governments to invest in nuclear energy (Sornette et al., 2019). However, innovation, new designs, and improved safety practices in nuclear power reactors have transformed nuclear power generation reactors into safe and reliable (Zeman et al., 2013). 51% of OECD countries with high nuclear energy capacity produce 85% of global nuclear energy (Nazlioglu et al., 2011). Sustainable energy policies will benefit the global community and individual nations by decarbonising the energy sector, reducing greenhouse gas emissions, combating climate change, and using nuclear energy to meet future energy needs.

The amount of gross capital per capita, one of the basic indicators used in the evaluation of the economic growth and development performance of countries (Prakash & Sethi, 2023), plays an important role in understanding the amount and distribution of investment in the economy of the country concerned (Topcu et al., 2020). Gross capital accumulation per capita is important for sustainable economic growth in countries.

High levels of gross capital accumulation, together with other factors in the relevant ecosystem, establish the necessary climate for economic growth and development (Onyinye et al., 2017). Capital accumulation is a natural consequence of investment behavior (Meng et al., 2022).

One of the factors that support growth and development by ensuring the sustainability of economic activities in terms of production, consumption, and capital accumulation in national economies is domestic loans extended by banks to the private sector (Thiel, 2001). Domestic credits to the private sector support the formation of competitive markets, enabling private investments and enterprises to be realized increasing productivity and generating higher levels of income (Mamman & Hashim, 2013). Loans to the private sector play an important role in the development of new investment areas and financing entrepreneurship (Szirmai et al., 2011). Domestic loans continue to expand and function when compared to other economic elements. It is important to maintain this equilibrium to avoid inflation, speculative asset and credit bubbles, debt crises, resource allocation distortion, and financial instability of national economies (Arteta & Hale, 2006; Mbate, 2013; Baron & Xiong, 2016; Katusiime, 2018). The amount of domestic credit that banks provide to the private sector per capita is a crucial indicator of capital accumulation, stability, and sustained economic activity (ECB., 2017; Wu et al., 2022).

Investments in nuclear energy are important for achieving sustainability and diversifying energy supply (Adamantiades & Kessides, 2009). The development of nuclear energy resources can have an impact on employment and growth in the energy sector, depending on capital accumulation. Bank loans to the private sector for financing and developing the energy industry can ensure the sustainability of investments in this area and promote the sector's growth (Choudhury et al., 2023). This scenario could promote capital accumulation in the energy sector, potentially resulting in reduced usage of fossil fuels and lower greenhouse gas emissions.

This study examines and evaluates the relationship between nuclear energy and domestic lending to the private sector, as well as per capita gross capital accumulation. The main goal of this study is to understand the effects of domestic credit and capital accumulation on nuclear energy in the participating nations. The study aims to provide insights for policy makers who want to combat climate change by reducing greenhouse gas emissions. The findings may also impact the financial decisions of nations that aim to invest in nuclear energy by reducing their reliance on fossil fuels. This study will review the literature on the topic and examine the direction and cause of the variables' relationship.

1. LITERATURE REVIEW

Various methods have been employed in the literature to investigate topics such as gross capital accumulation, economic growth, economic development, nuclear energy, renewable energy, carbon emissions, environmental quality, carbon footprint, financing costs, climate change, and global warming. These methods include Fourier analysis, panel data analysis, Panel VAR analysis, and ARDL analysis (Dong et al., 2018; Topcu et al., 2020; Aslan & Altinoz, 2021; Azam et al., 2021; Kartal et al., 2023; Qamruzzaman, 2024). The studies in the literature have mainly evaluated the relationship between renewable energy resources and various financial indicators. Some examples from the studies in the literature are presented below.

Dong et al. (2018) investigated the causal relationships between carbon dioxide emissions per capita, gross capital accumulation per capita, fossil fuel consumption per capita, nuclear energy per capita, and renewable energy consumption per capita for China using the ARDL test and the VECM Granger causality test. The study suggests that China has the potential to replace fossil fuels with nuclear and renewable energy sources. The analysis of the study led to the following conclusions: the use of fossil fuels will increase carbon dioxide emissions in both the short and long term. On the other hand, the use of nuclear and renewable energy will improve environmental quality. However, the long-term impact of these energy sources on carbon dioxide emissions may be minimal. Additionally, switching from fossil fuels to clean energy may be challenging due to low energy efficiency and renewable energy infrastructure.

Topcu et al. (2020) conducted panel causality tests to examine the relationship between economic growth and gross capital accumulation, energy consumption, and natural resource use. The study found a bidirectional association between gross capital accumulation and economic growth in both high-income and low-income nations. It has been discovered that in low- and middle-income nations, natural resources and economic growth have a bidirectional causal relationship. Measures of economic growth may include gross capital accumulation and energy consumption, depending on the structural attributes and developmental stage of specific nations.

Aslan and Altinöz (2021) conducted a PVAR analysis to investigate the relationship between natural resources, gross capital accumulation, globalisation and economic growth in developing economies across four continents from 1980 to 2018. The study found a bidirectional causal relationship between globalization and economic growth in each country examined. Natural resources were found to have a positive impact on the economies of all nations, except for those in Africa. In contrast to African countries, gross capital accumulation positively impacts economic growth in Europe, Asia, and the America.

Azam et al. (2021) investigated the effects of natural gas, nuclear energy, and renewable energy on GDP and carbon emissions in the ten nations with the highest carbon dioxide emissions ("China, the US, Canada, Germany, India, Russia, Korea, Iran, and the UK") using panel data analysis spanning the 1990–2014 period. This study found a long-term equilibrium relationship between the variables. For countries that emit, a short-term causal relationship exists between GDP and the consumption of nuclear energy and natural gas, supporting the growth hypothesis.

Imran et al. (2023) examined the impact of "green finance" initiatives created for the development of renewable energy on the development of nuclear energy. The study revealed that increasing the importance given to the field of energy finance will contribute to the development of nuclear energy and improve regional environmental quality. Ihsan et al. (2022) similarly found that green finance and nuclear energy consumption contribute positively to environmental security. These studies reveal that green finance serves the purpose of sustainable environment by increasing the volume of nuclear energy.

The study by Liu et al. (2023) reveals that green finance serves the goal of reducing the volume of carbon emissions through nuclear energy demand. The empirical results are noteworthy in terms of revealing the importance of the finance-nuclear energy nexus in combating climate change.

Qamruzzaman (2024) investigated the connections between foreign direct investment, gross capital accumulation, financial development, and the usage of renewable energy using the CS-ARDL and NARDL co-integration tests. The analysis highlights the significance of foreign direct investment in renewable energy. The significance of the role that foreign direct investment (FDI) and gross capital accumulation play in boosting the use of renewable energy is highlighted by the statement that financial development may allow investments in sustainable energy sources and foster innovations.

As can be seen from the studies briefly mentioned above, there are various studies in the literature on the relationship between nuclear energy, economic growth and development, renewable energy, and gross capital accumulation. Given the importance of capital accumulation and domestic credits for energy markets, it is surprising that only a limited number of empirical studies have investigated the relationship between nuclear energy and finance (capital accumulation and domestic credits to the private sector). To the best of our knowledge, there is no study in the literature that examines the relationship between the per capita amount of loans extended by banks to the private sector, gross capital per capita, and nuclear energy to understand the dynamics and effects of the finance and energy sectors on ecological and economic sustainability. This study is expected to contribute to the related literature in this respect.

2. MODEL AND DATA

To determine whether the development in the volume of nuclear energy (kWh-equivalent) has an impact on finance, the panel model with all variables included in the analysis is constructed as in equation (1).

$$NUC_{it} = a_i + \beta_1(CRD)_{it} + \beta_2(CAP)_{it} + \varepsilon_{it} \quad (1)$$

In the model, t=1970-2022 time period, i=1, 2, 3, …, 11 number of countries, εit is the error term, αi is country-specific fixed effects, NUC is nuclear volume per capita (kWh-equivalent), CRD is domestic credit extended by banks to the private sector (per capita), and CAP is gross capital formation (per capita). β_1 and β_2 correspond to the long-run elasticity coefficients of the variables. The variables used in this study are shown in Table 1.

Table 1. Variables

Variables	Notation	Source
Nuclear per capita (kWh - equivalent)	NUC	https://ourworldindata.org
Domestic credit to private sector by banks (per capita)	CRD	Basic Resource https://databank.worldbank.org
Gross capital formation (per capita)	CAP	Additional Resources https://fred.stlouisfed.org https://tradingeconomics.com https://data.oecd.org

In the analysis, the data of the countries with nuclear power generation capacity in the 1970–2022 period and for which complete data are available are used. A summary of the descriptive statistics of the variables is presented in Table 2.

Table 2. Descriptive Statistics

	NUC	CRD	CAP	NUC	CRD	CAP	NUC	CRD	CAP
		Canada			India			Switzerland	
Mean	8.5682	9.8454	8.4671	3.2279	4.9555	4.9125	8.8296	10.8716	9.2165
Median	8.8430	9.7259	8.4307	3.1882	4.5381	4.6350	9.0840	10.9748	9.3674
Maximum	9.2577	11.6283	9.5527	4.4139	7.0285	6.6179	9.2505	12.0410	10.1573
Minimum	4.9220	7.2152	6.8189	1.5034	2.5322	3.0151	6.4539	9.5710	7.4014
Std. Dev	0.7807	1.2423	0.7310	0.8437	1.3280	1.0769	0.6036	0.8319	0.7491
Skewness	-2.7718	-0.2727	-0.2565	-0.1943	0.1297	0.1087	-2.3379	-0.2235	-0.7261
Kurtosis	11.5099	2.1001	2.2257	1.8454	1.9124	1.8025	8.5823	1.6477	2.5069
Jargue-Bera	227.7891	2.4451	1.9048	3.2772	2.7609	3.2711	117.0985	4.4795	5.1945
Proability	0.0000	0.2945	0.3858	0.1943	0.2515	0.1948	0.0000	0.1065	0.0745
Observations	53	53	53	53	53	53	53	53	53
		Japan			Germany			Netherlands	
Mean	7.5854	10.1564	8.7448	7.9534	9.7517	8.4682	6.3634	9.7267	8.5041
Median	8.1225	10.5596	9.1418	8.2470	10.1873	8.7314	6.5323	10.0121	8.7159
Maximum	8.8988	11.2385	9.5231	8.6886	10.6975	9.4087	6.7374	11.0697	9.4669
Minimum	4.5205	7.6360	6.7964	5.4146	7.4057	6.8057	4.2402	6.7943	6.7684
Std. Dev	1.2744	0.9354	0.7525	0.8690	0.9314	0.7104	0.5334	1.2181	0.7588
Skewness	-0.7979	-1.1207	-1.1971	-1.4761	-0.9390	-0.7345	-3.1347	-0.7112	-0.6219
Kurtosis	2.3949	3.1888	3.1646	4.4580	2.6560	2.3717	11.9714	2.4956	2.2870
Jargue-Bera	6.4317	11.1733	12.7191	23.9402	8.0503	5.6377	264.5394	5.0302	4.5394
Proability	0.0401	0.0037	0.0017	0.0000	0.0179	0.0597	0.0000	0.0809	0.1033
Observations	53	53	53	53	53	53	53	53	53
		Spain			Sweden			France	
Mean	7.6132	9.2562	7.9353	9.2806	9.6712	8.7755	9.0872	9.6390	8.3966
Median	8.0676	9.2834	8.2174	9.7586	9.3753	8.8154	9.6919	9.7557	8.5495
Maximum	8.3857	11.0152	9.2207	10.1403	11.3261	9.6796	9.9341	10.8374	9.3041
Minimum	4.3503	6.6541	5.8400	2.9854	7.4624	7.3535	5.7706	7.4760	6.5268
Std. Dev	0.9684	1.2010	0.9008	1.4819	1.2237	0.6562	1.2047	0.9051	0.7545
Skewness	-1.4083	-0.3178	-0.6520	-3.0177	-0.0295	-0.4455	-1.4556	-0.5917	-0.7564
Kurtosis	4.0719	2.0444	2.3482	11.8801	1.6345	2.1988	3.5821	2.4199	2.6728
Jargue-Bera	20.0568	2.9087	4.6928	254.5825	4.1252	3.1706	19.4633	3.8362	5.2903
Proability	0.0000	0.2336	0.0957	0.0000	0.1271	0.2049	0.0001	0.1469	0.0710
Observations	53	53	53	53	53	53	53	53	53
		United States			United Kingdom				
Mean	8.5017	9.5138	8.6520	7.9070	9.5940	8.1990			
Median	8.8036	9.5372	8.7801	7.9344	10.1047	8.4354			
Maximum	8.9862	10.5822	9.7352	8.4827	11.4090	9.1481			
Minimum	5.7841	7.8626	7.0219	7.1902	6.1424	6.3509			
Std. Dev	0.6952	0.7385	0.7275	0.3655	1.6020	0.7917			
Skewness	-2.2843	-0.5420	-0.6445	-0.2063	-0.7138	-0.7913			
Kurtosis	7.9540	2.2974	2.4290	2.0139	2.0712	2.4472			
Jargue-Bera	100.2904	3.6849	4.3892	2.5234	6.4050	6.2060			
Proability	0.0000	0.1584	0.1114	0.2832	0.0407	0.0449			
Observations	53	53	53	53	53	53			

When the results of Table 2 are evaluated, it is seen that the largest mean value is Switzerland (10.8716), and the smallest mean value is India (3.2279). Again, the largest maximum value is Switzerland (12.0410), and the smallest maximum value is India (4.4139).

3. METHODOLOGY

The variables in the model will be subjected to more than one test to determine the relationship between the variables. Panel data analysis constitutes the basis of the tests to which the variables will be subjected.

To determine and apply the most appropriate test in the process of performing panel data analysis, two separate preliminary tests should be performed first. The first of these tests is the horizontal cross-section dependence test and the second is the homogeneity test. The Langrange multiplier test in equation (2), developed by Breusch and Pagan (1980), was first used to test for horizontal cross-section dependence.

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(\hat{p}_{ij}^{2}) \quad X^{2}{}_{\frac{N(N-1)}{2}} \tag{2}$$

The LM test in equation (2) was developed by Pesaran (2004) for cases where both (N) and (T) are large and transformed into the CDLM test in equation (3). Equation (3) developed by Pesaran (2004) is also used to detect horizontal cross-section dependence.

$$CD_{LM} = \left(\frac{1}{N(N-1)}\right)^{\frac{1}{2}} \sum_{i=1}^{N-1}\sum_{j=_i+1}^{N}\left(T\,\hat{p}_{ij}{}^{2}-1\right) \tag{3}$$

Moreover, the versions of the CDLM test developed by Pesaran et al. (2008) and Pesaran and Yamagata (2008) are included in the analysis. After analyzing the horizontal cross-section dependence, the homogeneity of the slope coefficients is investigated using the formulations found by Swamy (1970) and developed by Pesaran and Yamagata (2008), as shown in equations (4) and (5).

$$\tilde{\Delta}= \sqrt{N}\,\frac{N^{-1}\tilde{S}-k}{\sqrt{2k}} \tag{4}$$

$$\tilde{\Delta}_{adj}= \sqrt{N}\left(\frac{N^{-1}\tilde{S}-E\left(\tilde{Z}_{it}\right)}{\sqrt{Var(\tilde{Z}_{it})}}\right) \tag{5}$$

After conducting the preliminary tests required for panel data analysis, the unit root test was conducted as the second step. At this stage, the smooth transition Fourier panel unit root test including Fourier functions developed by Nazlioglu and Karul (2017), which has important advantages, is used. The formulas used for this test are given in equations (6), (7), and (8).

$$\Delta y_{it} = \delta_{0i} + \delta_{1i}\Delta\sin\left(\frac{2\pi kt}{T}\right) + \delta_{2i}\Delta\cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_{it} \tag{6}$$

$$P_{LM}(k) = N^{-1}\sum_{i=1}^{N}\tilde{\tau}_i(k) \tag{7}$$

$$Z_{LM}(k) = \frac{\sqrt{N}(P_{\tau}(k)-\xi(k))}{\zeta(k)} \sim N(0,1) \tag{8}$$

After conducting the unit root test, we employed the fractional frequency flexible Fourier form panel co-integration test developed by Olayeni et al. (2020) in the third stage to ascertain the long-run relationship of the variables. Equation (9) presents the formulation for this test.

$$\tilde{v}_{i,t} = \hat{v}_{i,t} - \hat{\alpha}_i - \hat{\chi}_i\sin\left(\frac{2\pi kt}{T}\right) - \hat{\varphi}_i\cos\left(\frac{2\pi kt}{T}\right) \tag{9}$$

In the fourth stage, where the long-run coefficients are estimated in the model in which the co-integration relationship between the variables is determined, the co-integration estimator developed by Bai (2009), which considers the interactive fixed effects (Interactive Fix Effect-IFE), is used with the help of equations (10), (11) and (12).

$$Y_{it} = X'_{it}\,\beta + \alpha_i + \xi_t + \varepsilon_{it} \tag{10}$$

$$\lambda'_i\,F_t = \alpha_i + \xi_t \tag{11}$$

$$SSR\,(\beta, F, \lambda) = \sum_{i=1}^{N}(Yi - Xi\,\beta - F\lambda i)'\,(Yi - Xi\beta - F\lambda i) \tag{12}$$

4. EMPIRICAL RESULTS

To conduct panel data analysis, horizontal "cross-section dependence and homogeneity of slope coefficient tests" should be performed first. In this context, the findings of the tests for horizontal cross-section dependence and homogeneity of slope coefficients are presented in Table 3.

Table 3. Cross-Sectional Dependence Tests

Test	**Cross-Sectional Dependence Lagrange Multiplier 1**		**Cross-Sectional Dependence Lagrange Multiplier 2**		**Cross-Sectional Dependence Lagrange Multiplier 3**		**Cross-Sectional Dependence Lagrange Multiplier Adjusted**	
Variable	**Statistic**	**Prob**	**Statistic**	**Prob**	**Statistic**	**Prob**	**Statistic**	**Prob**
NUC	578.059	0.000	49.872	0.000	-4.508	0.000	38.953	0.000
CRD	615.120	0.000	53.405	0.000	-4.734	0.000	37.115	0.000
CAP	585.146	0.000	50.547	0.000	-4.714	0.000	22.185	0.000
Panel	1883.630	0.000	174.353	0.000	174.353	0.000	192.608	0.000
Slope Homogeneity Test			**Statistic Value**				**Probability Value**	
Delta Tilde			-2.087				0.982	
Delta Tilde Adjusted			-2.149				0.984	

Cross-Sectional Dependence Lagrange Multiplier 1 (Breusch & Pagan, 1980), Cross-Sectional Dependence Lagrange Multiplier 2 and Cross-Sectional Dependence Pesaran (2004), Cross-Sectional Dependence Lagrange Multiplier Adjusted Pesaran et al. (2008), Delta Tilde and Delta Tilde Adjusted Pesaran and Yamagata (2008). Moreover, "***, ** and *" indicate significance at "1%, 5% and 10%" levels, respectively.

Table 3 shows that the probability values of the tests for the dependent variable, independent variables, and overall panel are "0.00". This empirical result leads to the conclusion that the variables are cross-sectionally dependent. The results of the Delta Tilde and Delta Tilde Adjusted tests show that the probability values are insignificant, i.e., greater than "0.05". This result leads to the conclusion that the slope coefficients are homogeneous.

In the next stage, unit root tests were conducted.

Table 4. Unit Root Test

	NUC	**CAP**	**CRD**
Canada	-4.2456	-5.7888	-7.0682
Switzerland	-4.3759	-4.8098	-4.2869
Germany	-3.1412	-3.2777	-2.9085
Spain	-2.2395	-2.4057	-2.2236
France	-1.4547	-1.7179	-1.3461
United Kingdom	-0.618	-0.3469	-0.6949
India	0.3486	-0.682	-0.5488
Japan	-0.3927	-0.7489	-0.6313
Netherlands	-0.1321	-0.671	-0.626
Sweden	-1.0239	-1.1306	-1.0984
United States	-1.5891	-2.189	-3.7059
PLM	-1.7149	-2.1608	-2.2853
ZLM	1.8061	-0.4489	-1.0790
P. Val.	0.9645	0.3267	0.1403

According to the results of the smooth transition Fourier panel unit root test, all of the variables used for panel data analysis are found to contain a unit root at the level value. The results of the Fourier panel co-integration test applied to the variables are given in Tables 5 and 6.

$Model\ 1.1: NUC_{it} = a_i + \beta_1 (CRD)_{it} + \varepsilon_{it}$

Table 5. Fourier Co-integration Test

	GLS				PP			
	Stat	**1%**	**5%**	**10%**	**Stat**	**1%**	**5%**	**10%**
Canada	-5.061***	-2.975	-1.783	-0.045	-5.73***	-3.212	-2.213	-0.58
Switzerland	-5.594***	-2.679	-1.81	0.081	-6.304***	-3.114	-2.251	-0.298
Germany	-6.185***	-2.91	-1.698	-0.024	-6.316***	-3.356	-2.127	0.941
Spain	-1.84**	-2.405	-1.478	-0.129	-5.641***	-2.885	-2.072	0.489
France	-4.628***	-2.536	-1.595	0.625	-5.34***	-2.949	-2.111	0.388
United Kingdom	-6.556***	-2.788	-1.776	0.122	-6.629***	-3.006	-2.116	-0.056
India	-2.354***	-2.709	-1.589	-0.601	-7.625***	-3.228	-2.062	-0.318
Japan	-5.331***	-2.653	-1.273	1.303	-5.739***	-2.748	-1.449	1.32
Netherlands	-0.877*	-3.321	-1.995	-0.564	-12.152***	-4.156	-2.542	-0.629
Sweden	-7.415***	-2.687	-1.823	-0.619	-7.789***	-3.399	-2.343	-0.163
United States	-4.932***	-2.286	-1.636	-0.254	-4.998***	-2.647	-2.02	-0.098

"***, ** and *" indicate significance at the "1%, 5% and 10%" levels, respectively.

Based on the outcomes of the panel Fourier co-integration test, the presence of a cointegration relationship is observed in all panel countries, as indicated by both PP and GLS values. These results imply a persistent relationship between the volume of domestic credit (per capita) extended by banks to the private sector and the volume of nuclear (kWh-equivalent) per capita.

$Model\ 1.2: NUC_{it} = a_i + \beta_1 (CAP)_{it} + \varepsilon_{it}$

Table 6. Fourier Co-integration Test

	GLS				PP			
	Stat	**1%**	**5%**	**10%**	**Stat**	**1%**	**5%**	**10%**
Canada	-4.811***	-2.69	-1.401	1.102	-4.948***	-2.812	-1.782	0.815
Switzerland	-4.098***	-2.373	-1.437	0.98	-5.83***	-2.792	-1.781	1.112
Germany	-5.499***	-2.529	-1.382	1.704	-5.36***	-3.022	-1.689	1.484
Spain	-4.166***	-2.23	-1.284	0.322	-5.62***	-2.805	-1.551	0.326
France	-4.465***	-2.766	-1.394	0.446	-5.306***	-2.726	-1.503	0.995
United Kingdom	-5.206***	-2.377	-1.28	2.711	-6.108***	-2.553	-1.63	1.685
India	-4.851***	-2.617	-1.755	-0.35	-7.231***	-3.752	-2.443	-0.568
Japan	-5.185***	-2.511	-1.073	0.739	-5.894***	-2.598	-1.67	0.266
Netherlands	-2.332***	-2.157	-1.262	0.941	-6.322***	-2.347	-1.563	0.436
Sweden	-3.746***	-2.193	-1.441	0.824	-5.748***	-2.491	-1.477	1.026
United States	-4.601***	-2.301	-1.513	0.129	-5.624***	-2.919	-2.03	0.633

"***, ** and *" indicate significance at the "1%, 5% and 10%" levels, respectively.

A cointegration relationship was identified in all panel countries based on the results of the panel Fourier co-integration test, according to both PP and GLS values. These findings suggest a long-lasting relationship between gross capital formation (per capita) and nuclear (kWh-equivalent) volume per capita.

When the results are evaluated together, there is a significant relationship between the relevant variables and the volume of nuclear (kWh - equivalent) per capita for both important indicators of the financial sector. Since co-integration relations are detected in the model, the coefficient estimation of the relationship between the variables and the result of the analysis considering the fixed effects are given in Table 7.

Table 7. Panel Co-integration Estimation using Interactive Fixed Effects

	Coefficient	Std. Er.	P-value	%95 CV	Interval
Cons	-2.383735***	0.3664428	0.000	-3.119056	-1.648414
CRD	-0.4580172***	0.1508787	0.004	-0.7607774	-0.155257
CAP	1.753663***	0.2123953	0.000	1.32746	2.179865

According to the results of the panel co-integration coefficient estimates, the CRD variable has a negative and statistically significant effect on the NUC variable. However, the CAP variable has a statistically significant and positive effect on the NUC variable.

CONCLUSION

The use of nuclear energy and green energy sources for sustainable development are important research topics of today. Many countries are looking for ways to transition from traditional carbon-based fuels to clean energy sources. Undoubtedly, nuclear energy stands out among these sources because of its energy cost advantage and being an important clean energy source, although its initial investment cost is high. While nuclear energy supports the sustainable development process, it is inevitable that it will interact with financial markets. In this framework, the main purpose of this study is to reveal the relationship between the volume of nuclear energy, which is becoming increasingly important as a clean energy source, and financial indicators within the scope of nuclear energy producing countries in today's world, where the effects of environmental pollution are widely discussed, and sustainable development targets are established. Within the scope of the study, the period 1970–2022 is considered, and the relationship between domestic credit (per capita) and gross capital formation (per capita) variables given by banks to the private sector and the volume of nuclear energy per capita is analyzed. In this study, after basic analyses of panel data consisting of nuclear energy producing countries, the long-run relationship between the variables was determined using the fractional frequency flexible Fourier form panel co-integration test developed by Olayeni et al. (2020). In addition, coefficients were calculated using the co-integration estimator proposed by (Bai, 2009).

The results of the analysis revealed a co-integration relationship in all panel countries according to both PP and GLS values. These results clearly show a long-term relationship between gross capital formation per capita and nuclear (kWh-equivalent) volume per capita. According to the results of the panel co-integration coefficient estimates, the CRD variable has a negative and statistically significant effect on the NUC variable. However, the CAP variable had a statistically significant and positive effect on the NUC variable. The findings of this study may contribute to the financial decisions of countries that want to focus on nuclear energy investments by reducing fossil fuels, and understanding the relationship between nuclear energy and finance may contribute to policy makers who want to combat climate change by reducing greenhouse gas emissions. The results of the analysis provide important indicators for countries that are currently using nuclear energy as well as for countries that are looking for green energy alternatives to support the sustainable development process. It will be an important gain of this study to put the issue of supporting the financial field, which is indispensable for the development process, with nuclear energy on the agenda of country policy makers.

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