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Examining the Role of Nuclear Energy and Financial Development on Biodiversity Risk in France: New Evidence from NARDL

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Abstract: This study aims to investigate the nonlinear effect of nuclear energy, economic complexity, and financial development on biodiversity in France using the NARDL. Unlike other traditional proxies of ecological quality (CO2 and EF), this study utilized the "Biodiversity habitat index". The analysis revealed that positive shocks in nuclear energy led to sustainable biodiversity in France. Moreover, negative shocks from nuclear energy led to biodiversity losses both in the short and long term. Moreover, financial development and economic complexity were found to exhibit favorable conditions for biodiversity in the long term. Contrarily, economic growth accelerates biodiversity loss in France. Policymakers should endeavor to promote investments in nuclear energy, green finance, and implementation of climate-related risk management frameworks.

Keywords: biodiversity, economic complexity, financial development, NARDL, nuclear energy.

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INTRODUCTION

Biodiversity is undergoing its worst decline in human history, and triggers of this reduction are worsening (NGFS & INSPIRE, 2022). According to Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the majority of ecosystem and biodiversity indicators are declining, one-quarter of species are threatened, and approximately 1 million species are at risk of extinction (IPBES, 2019). "Such declines are undermining nature's productivity, resilience and adaptability, and are in turn fueling extreme risk and uncertainty for our economies and well-being", claims the UK government's Dasgupta Review of the Economics of Biodiversity (Dasgupta, 2021). Platto et al. (2021) postulated that degradation of natural ecosystems, most notably through deforestation and changes in land usage, contributed to the outbreak such as COVID-19 pandemic. The loss of biodiversity worldwide has not yet been slowed by policy initiatives, and none of the 20 biodiversity targets set by governments in a 10-year plan in 2010 had been entirely fulfilled by 2020 (Colwell & Coddington, 1994). The Sustainable Development Goals (SDGs) and attempts to combat climate change are at risk due to this failing to acknowledge that "we are immersed in Nature (Alola & Adebayo, 2023).

Nuclear energy (NC) is considered to be an effective mechanism against ecological deprivation (Kartal et al., 2023). According to Baek (2016) NC is at the "heart of zero-emission scenarios" since it is the most treasured energy base on resource utilization, CO_2 emissions, and economic expansion. Due to its ability to generate less carbon electricity, NC has succeeded in one of the most powerful mechanisms in mitigating degradation (Kamal et al., 2021). According to (IEA, 2021) between 2019-2021 one yearly basic, nuclear plants have prevented the emission of 1.5-2 billion tons of greenhouse gases. Due to its importance, global authorities planned to increase NC electricity to account for 25% of global electricity by 2050 (Yang et al., 2021). Contrarily, NC may also pose some environmental risks. Sadiq et al. (2022) propounded that concern surrounding the implementation of nuclear plants includes "economic performance, the proliferation of dangerous material, the peril of terrorism, operation safety, and radioactive waste disposal"; these risks add to the low social espousal. Moreover, there is a risk of reactor catastrophes which can trigger prevalent ecological and health consequences and the rerouting of nuclear equipment for "military or terrorist" activities also contributed to the hitches of NC (Mahmood et al., 2020). Furthermore, "nuclear power generation includes high external costs to secure nuclear facilities against terrorist attacks, store highly radioactive waste, pay for insurance against the cost of sudden accidents and apply safeguards to sensitive activities such as fuel making" (Usman & Hammar, 2021). Based on cost-benefit analysis, it appears that NC will remain in this fight against climate change.

Another vital indicator that may impact biodiversity is the complexity of an economy. Thus, we introduce the EC (economic complexity index) of Hidalgo & Hausmann (2009) to estimate an economy's technologically intensive export composition. Moreover EC measures the level of skill sophistication needed by an economy in the production of goods (Doğan et al. 2019). EC also reveals a nation's export in terms of the level of erudition and diversity. Certainly, "in complex economies, more diverse products are produced with more comprehensive knowledge and skills" vis-a-vis (Nathaniel, 2021). Thus, EC is a pointer to economic development (Mishra et al., 2020). Therefore, EC may require higher energy demand due to the increase in the diversity of manufactured products which may trigger environmental deprivation (Balsalobre-Lorente et al., 2021). However, EC has the potential to mitigate environmental degradation, because it promotes R&D in clean technology (Neagu & Teodoru, 2019).

Financial development may affect biodiversity via various channels: a well-functioning financial market may promote intensive investments in R&D, and eco-friendly ventures (Shahbaz et al., 2016). Likewise, financial expansion may also lessen environmental harm through the "taxonomy regulation," which guides lending institutions to focus more on providing eco-friendly loans and investment (Adebayo et al.,2023). Vis-à-vis, …"banks may reduce lending to high-polluting sectors, and this transition may create an incentive for corporations to shift to green innovations. Furthermore, the environmental social and governance (ESG) classification and incentives may induce firms to embrace less energy-intensive ventures, thus improving air quality" (Joof et al., 2022). Contrarily, financial development can reduce biodiversity conservation because it stimulates high-income growth, enabling economic agents (firms and households) to increase their spending

(Baloch et al., 2019; Danish et al., 2018). When such spendings are not ethically motivated to consider the ecosystem, the result is detrimental to the environment due to ecological-unfriendly activities (non-renewable energy use and industrial practices).

Due to the aforementioned fact, the authors are motivated to investigate the dynamic impact of nuclear energy, economic complexity and financial development on biodiversity in France. The motive of this paper is to make the following contributions to the literature: Firstly, this is the premiere study to test the impact of nuclear energy, economic complexity and financial development on biodiversity in France, using a nonlinear ARDL. France is selected due to the fact that; it has upheld the "Paris Agreement global framework" to prevent the adverse consequences of "climate change" by controlling "global warming" below 2 C (Pata & Samour, 2022). With 56 nuclear plants in operation and an overall size of 61,370 MW, France is ranked the second leading NC "nuclear power capacity" in the globe and NE production of about 70.6% in 2019, the largest in the globe (World Nuclear Association, 2022). Moreover, according to a study conducted by Banque de France, "42% of the value of securities held by French financial institutions comes from issuers that are highly or very highly dependent on one or more ecosystem services. The accumulated terrestrial biodiversity footprint of these securities is comparable to the loss of at least 130,000 km^2 of 'pristine' nature, which corresponds to the complete artificialization of 24% of the area of metropolitan France" (Svartzman et al., 2021). This points out that the economy of France is highly dependent on biodiversity. Secondly, the role of nuclear energy, economic complexity, and financial development have been examined on various ecological indicators (see: Neagu 2019; Balsalobre-Lorente et al., 2022). These papers used CO_2 emissions as a measure of environmental deterioration, which accounts for only air pollution. Likewise, Pata & Samour (2022) examined the role of nuclear energy on CO_2 emissions, ecological footprint, and load capacity factor in France; however, they ignored biodiversity. Therefore, we used "biodiversity habitat index (BHI) which estimate impacts of habitat loss, degradation and fragmentation on retention of terrestrial biodiversity globally, from remotely sensed forest change and land-cover change datasets (Wolf et al., 2022). The BHI is a positive ecological indicator, where a high BHI indicates high ecological quality vis-à-vis. Furthermore, the BHI is based on a score between 0-100, 100 reveals that a nation did not experience any loss of habitat while 0 shows total loss of habitat (Wolf et al., 2022). Finally, we employed the NARDL from 1988-2018 in order to provide the insightful policy implications on biodiversity drivers.

METHODS

The current study utilises the NARDL on annual series from 1988-2018, we use the biodiversity habitat index[1] as a measure of environmental quality. The description of the series are highlighted in Table 1, our log model is as follows:

$$InBD_t = \beta_0 + \beta_1 InNC_t + \beta_2 InEC_t + \beta_3 InFD_t + \beta_4 InGDP_t + \varepsilon_{it} \quad (1)$$

In Equation 1, $InBD_{it}$ is the depiction biodiversity in France, $InNC_{it}$ is the nuclear energy, $InEC_{it}$ denotes economic complexity, $InGDP_{it}$ is economic growth and $InFD_{it}$ is financial development. The decomposition of nuclear energy is geven below as per the NARDL in Equations (2):

$$InNC_t = InNC_0 + InNC_t^{+} + InNC_t^{-} \quad (2)$$

1 for more details on the construction of the biodiversity index see (Wolf et al. 2022; Hansen et al., 2013).

Table 1 Variables description and sources of data

Variables	Description	Source
InBD	Biodiversity Habitat Index	(Yale Center for Environmental Law & Policy, 2018)
$InEC_{it}$	The appearance of the productive composition of the country by combining the information on their variety and number of commodities it exports.	Atlas of Economic Complexity index (2018)
$InNC_{it}$	Alternative and nuclear energy (% of total energy use)	(WB, 2018)
$InFD_{it}$	Domestic credit to the private sector by banks (% of GDP)	(WB, 2018)
$InGDP_{it}$	GDP per capita	(WB, 2018)

To examine the effect of nuclear energy, economic complexity and financial development on biodiversity in France, the "panel nonlinear ARDL" proposed by Shin et al. (2014) is applied. This method is used based on the following features: it can be applied if all the series are integrated at the same or mixed order (i.e. either I(0) and or I(1)) but not I(2) (Pesaran et al., 2001). The NARDL is popular because many macroeconomic variables exhibit nonlinear behaviors due to the long period in the series. Furthermore, different from the "ARDL, the NADRL generates the focused variable into positive and negative". Finally, it has the an advantage of eliminating biasness and spurious analysis (Liu et al., 2017). In determining the stationarity of the series, we employed the Zivot & Andrew (ZA) (1992), and Clemente–Montañes–Reyes (1998) (CMR), which considers one and two structural breaks unlike the traditional unit root techniques.

In testing for cointegration, NARDL follow the same rule as Pesaran et al. (2001). The hypotheses: $H_0 = a_1 = a_2^+ = a_3^- = a_4^+ = a_5^- = a_6 = 0$ and $H_1 \neq a_1 \neq a_2^+ \neq a_3^- \neq a_4^+ \neq a_5^- \neq a_6 \neq 0$, based on equation (12) for the null and alternative, respectively, in equation (1.1) below. The presence (or absence) of cointegration is confirmed once the "F-statistic (Fpss)" is higher than the "critical values" at the upper bound (Ramzan et al.,2023). Equally, if the F-statistic is in the middle of the lower and upper bounds, it implies an indecisive outcome of cointegration. The long-run asymmetric equation of Shin et al. (2014) is represented in Eq. (3):

$$y_t = \delta^+ x_t^+ + \delta^- x_t^- + \pi_t \qquad (3)$$

Where, the dependent indicator is presented as y_t the parameter in the long run are the (δ^+ and δ^-) and the decomposition of the explanatory indicators are (x_t^+ and x_t^-) as shown in Equation (4-7):

$$x_t^+ = \sum_{i=1}^{t} \Delta x_i^+ = \sum_{i=1}^{t} \max(\Delta x_i, 0) \qquad (4)$$

$$x_t^- = \sum_{i=1}^{t} \Delta x_i^- = \sum_{i=1}^{t} \min(\Delta x_i, 0) \qquad (5)$$

Positive and negative sums decomposition of $InNC_t$.

$$InNC_t^+ = \sum_{t=1}^{t} \Delta InNC_i^+ = \sum_{i=1}^{t} = \text{Max}(\Delta\, InNC_t,\, 0) \qquad (6)$$

$$InNC_t^- = \sum_{t=1}^{t} \Delta InNC_i^- = \sum_{i=1}^{t} = \min(\Delta\, InNC_t,\, 0) \qquad (7)$$

Based on equations (1-7), the general form of the NARDL is presented as follows:

$$\Delta\gamma_t = \mu + \vartheta_y y_{t-1} + \vartheta_x^+ x_{t-1}^+ + \vartheta_x^- x_{t-1}^- + \sum_{i=1}^{m} \delta_i \Delta y_{t-1} + \sum_{i=0}^{n} (\lambda_i^+ \Delta x_{t-1}^+ + \lambda_i^- x_{i-1}^-) \qquad (8)$$

$$\Delta InBD_t = \alpha_0 + \alpha_1 InBD_{t-1} + \alpha_2^+ \Delta InNC^+ + \alpha_3^- \Delta InNC^+ + \alpha_3^- \Delta InNC^- + \alpha_4 EC_t + \alpha_5 InGDP_t + \alpha_6 FD_t + \sum_{i=0}^{q1} \alpha_{8i}^+ \Delta InNC_{1t-1}^+ + \sum_{i=0}^{q2} \alpha_{9i}^- \Delta InNC_{2t-1}^- + \sum_{i=0}^{q3} \alpha_{10i} \Delta InEC_{3t-1} + \sum_{i=0}^{q4} \alpha_{11i} \Delta InGDP_{4t-1} + \sum_{i=0}^{q5} \alpha_{12i} \Delta InFD_{5t-1} + \varepsilon_t \qquad (9)$$

Δ represent changes in the variables, ϑ^{+} and ϑ^{-} and λ^{+} and λ^{-} , denotes the "long-term and short positive and negative asymmetry coefficients", respectively (Shin et al., 2014). The medium-term effect of the InNC and InEC, GDP and FD on the biodiversity is showed in the short-term analysis, while the long run exhibits the "time and speed of adjustment" of the independent variables on the biodiversity. The "Wald test" determines asymmetries, the null proposition is the presence of symmetries ($\lambda^{+} = \lambda^{-}$).

RESULTS AND DISCUSSION

The findings of the unit roots tests displayed in Table 2 and 3, the findings illustrate that BD, FD, EC, GDP and NC are integrated and stationery at I(1). Therefore, the studied variables are integrated at the I(1) level. The outcomes of the "ARDL bound test of the co-integration" are shown in Table 4. The analysis affirm that the values of bound test F-statistic test exceed the CVs. These outcomes confirm that the "cointegration" among the BD, FD, EC, GDP and NC is valid.

Table 2 The Findings of the ZA unit root test

	Level			First Differences	
Variables	**$t.^{STAT}$**	**DSB¹**	**Variables**	**$t.^{STAT}$**	**DSB¹**
InDBt	−3.456	2001	$\Delta InBD_t$	−7.034*	2016
InFD	−3.651	2005	ΔInFD	−8.963*	2002
$InEC_t$	−2.751	1992	$\Delta InEC_t$	−8.005*	2008
$InNC_t$	−2.650	2009	$\Delta InNC_t$	−9.785*	2011
$InGDP_t$	−3.730	2009	$\Delta InGDP_t$	−7.785*	2008

"* means the significance of the variables at the 1% level. DSB means dates of structural break"

Table 3 The Results of the CMR unit root test

	Level				First Differences		
Variables	**$t.^{STAT}$**	**DSB¹**	**DSB²**	**Variables**	**$t.^{STAT}$**	**DSB¹**	**DSB²**
InDBt	−2.101	1996	2012	$\Delta InBD_t$	−8.176*	2014	2018
InFD	−2.965	1998	1999	ΔInFD	−7.786*	2014	2010
$InEC_t$	−2.765	2015	2018	$\Delta InEC_t$	−7.551*	2002	2008
$InNC_t$	−2.450	2009	2012	$\Delta InNC_t$	−8.001*	2010	2017
$InGDP_t$	−2.315	2002	2008	$\Delta InGDP_t$	−7.414*	2008	2009

"*means the significance of the variables at the 1% level. DSB means dates of structural break $tstatic_{-nv}$, and $Fstatic_{-nv}$ mean the F-test on all the lagged level variables; t-test on the lagged dependent variables, the F-test on the lagged independent variable respectively".

Table 4 Findings of the bound cointegration test

Test statistic	Value	Sig	Lower bound	Upper bound
F-statistic	7.203	10%	2.75	3.79
		5%	3.12	4.25
		1%	3.49	5.23

Table 5 shows the empirical findings of the short and long-run analysis from the nonlinear ARDL approach. The findings showed that an increase in FD led to increase biodiversity. This illustrates that ceteris paribus, a 1% positive shift in FD increase biodiversity by 0.8651%. These results align with the study of (Habiba & Xinbang, 2021). This result can be attributed to the level of financial maturity of the French financial system and the proactiveness of the Banque de France in introducing various mechanisms to promote intensive investments in R&D, and eco-friendly ventures. Similarly, France have been at the for front of the "taxonomy regulation", which guides lending institutions to focus more on providing eco-friendly loans and investments. Vis-à-vis, this regulation focuses banks to reduce their loan portfolios for high polluting sectors; this transition may create an incentive for corporation to shift to green innovations. Furthermore, the environmental social and governance (ESG) classification and environmental disclosures, may induce firms to embrace less energy intensive ventures, thus improving biodiversity.

Furthermore, the outcomes illustrate that EC contributes to an increase in biodiversity in the long run but decreases biodiversity in the short run. This ilusttates that ceteris paribus (holding other factors constant), a 1% increase in EC increase biodiversity by 0.157% in the long-run while a 1% decline in the short run reduces biodiversity by 0.439%. This is attributable to the fact that complex economies like France produce more diverse products higher knowledge, skills and technological expertise; therefore, resulting to a reduction in energy-intensive production and eventually improving biodiversity conservation.

Similarly, the analysis suggested that a positive change in NC contributes to a rise in biodiversity while a negative shock in NC decreases biodiversity. This highlightes that ceteris paribus, a 1% positive shift in NC increase biodiversity by 0.0866% and 0.590% in the short and long run while a 1% negative shift lessens biodiversity by 0.305% and 0.061% in the short and long run, respectively. These findings align with the study of (Pata & Samour, 2022), who highlighted that nuclear energy improves the quality of the environment. The results affirmed a U-Shaped association between nuclear energy and biodiversity. The positive shock of nuclear energy on biodiversity is favorable to the ecosystem due to the fact that France is ranked as the second largest 'nuclear power capacity' in the world, with 56 nuclear plants in operation and an overall size of 61,370 MW. Moreover, it has a nuclear energy production of about 70.6% in 2019, the largest in the globe (World Nuclear Association, 2022). And according to Baek (2016), NC is at the "heart of zero-emission scenarios". Furthermore, between 2019-2021, one a yearly basics, nuclear plants have prevented the emission of 1.5-2 billion tons of greenhouse gases (IEA, 2021). However, economic growth was found to obstruct biodiversity conservation in France. This is affirming the analysis and Jahanger et al. (2022) for South Africa.

Table 5 Findings of Nonlinear ARDL

	Long run			Short run		
	Coefficient	T-statistics	P-value	Coefficient	T-statistics	P-value
FD	0.410***	6.850	0.00	0.264*	2.139	0.07
GDP	-0.609***	-8.869	0.00	-0.753***	-4.943	0.00
EC	-0.157***	-5.811	0.00	-0.439***	-4.839	0.00
NC+	0.590***	5.402	0.00	0.866**	2.388	0.04
NC⁻	-0.061***	-4.388	0.00	-0.305*	-2.303	0.05
ECT(-1)				-0.601***	-7.272	0.00

"Note: ***, ** and * signifies 10%, 5% and 1% level of significance

Table 6 Diagnostic tests

Test	Probability
Heteroskedasticity assessment (White test)	0.763
(Breusch-Godfrey assessment)	0.420
Normality assessment	0.581
Ramsey-Reset assessment	0.548

ECT_{t-1} means that the production functions shift to a long-run equilibrium path, with a 60.1% speed adjustment from the short term to the long term. To ensure the stability of the model employed in the current work, some diagnostic tests are applied, along with "CUSUM and CUSUM square assessments". The results of the diagnostic assessments are in Table 6. The results of the "Breush–Pagan–Godfrey heteroscedasticity test" reinforced the absence of "serial correlation" in the studied model. Similarly, the "normality test" reinforced that the model studied is "normally distributed", and the "Ramsey RESET test" reinforced that the model is statistically stable. The "CUSUM test and CUSUM square" assessments are shown in Figure 1. It illustrates that the blue line falls between the green and red lines. Thus, the figure affirmed that the model of the current work is formulated correctly.

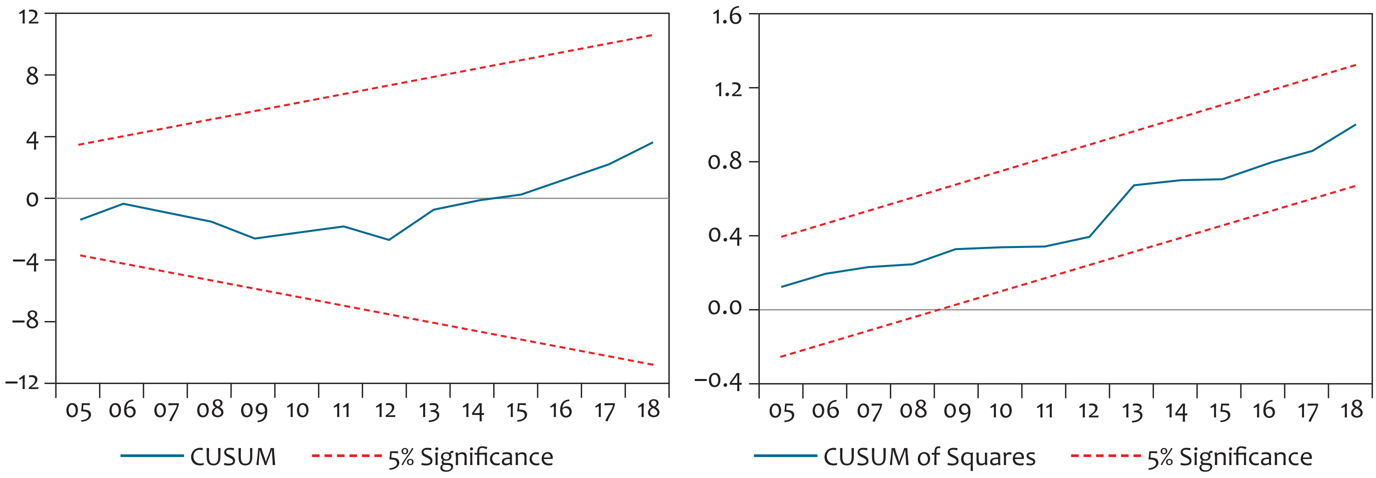

Figure 1 CUSUM and CUSUM square tests

The causal interrelation assists in crafting suitable recommendation for the environmental sustainability in France. The findings of Table 7 show that there is a one-way causal interaction that runs from FD, EC and GDP to biodiversity. Similarly, the results showed a unidirectional causation from a positive shocks in NC to biodiversity.

The unprecedented biodiversity risks facing the globe is a threat to food security and water sustainability, because such services are provided by the biosphere. Thus, this research looks at the link between nuclear energy, economic complexity, financial development and biodiversity in France using the nonlinear ARDL from 1988 to 2018. To this purpose, we used Zivot & Andrew (1992) (ZA) and Clemente–Montañes–Reyes (1998) structural break unit root test to evaluations to determine data stationarity. The NARDL of Shin et al. (2014) was applied to determine positive and negative shocks of the independent variables on biodiversity. The results of unit root tests show that all variables are stationary and the results of cointegration tests show that the variables have a long-run relationship. The outcome obtained from NARDL illustrated that a positive shock in nuclear energy contributes to an increase in biodiversity while a negative shock in nuclear energy decreases biodiversity both in the short and long run. Moreover, financial development promotes biodiversity. Furthermore, economic complexity promotes biodiversity in the longrun while economic growth was found to increase biodiversity loss. The results of the Granger causality test showed that there is a causal interaction from FD and EC and GDP to biodiversity. Similarly, a unidirectional causal interaction moving from positive shocks in NC to biodiversity was found.

Table 7 Findings of the Granger Causality Assessment

	F-Statistic
FD causes BD	3.984**
BD causes FD	1.636
EC causes BD	7.655***
BD causes EC	1.778
NC+ causes BD	4.329**
BD causes NC+	0.295
NC– causes BD	0.641
BD causes NC–	0.412
GDP causes BD	6.042***
BD causes GDP	0.275

"Note: + and – means the cumulative function of positive (+) and negative (-) changes, respectively. *** and ** respectively means significance levels of 1% and 5%".

Following our analysis, the following policy recommendations can be made: 1) France should continue to intensify its nuclear energy capacity, while monitoring and mitigating its probable effects on the environment; 2) French authorities could apply "Pigovian taxes" on traditional firms and subsidized firms that adheres to clean technologies; 3) ensure continuous support for reneable energy technologies; 4) the French authorities must endeavor to reconstructing the country's export baskets, with lower energy-intensive goods, 5) promote and strengthen financial development, 6) embrace environmental social and governance (ESG) considerations and environmental disclosures, to induce banks to lend to energy intensive ventures, thus improving biodiversity; 7) strengthen and enforce taxonomy regulations.

CONCLUSION

Our findings revealed that nuclear energy, economic complexity, and financial expansion play a major role in influencing the pattern of biodiversity and can serve as an effective tool in mitigating biodiversity risk. The positive shock of nuclear energy on biodiversity is favorable to the ecosystem due to the fact that France is ranked as the second largest "nuclear power capacity" in the world, with 56 nuclear plants in operation and an overall size of 61,370 MW. Moreover, it has a nuclear energy production of about 70.6% in 2019, the largest in the globe (World Nuclear Association, 2022). And according to Baek (2016) NC is at the "heart of zero-emission scenarios". Furthermore, between 2019-2021, one a yearly basics, nuclear plants have prevented the emission of 1.5–2 billion tons of greenhouse gases (IEA, 2021). Furthermore, EC improves biodiversity, which is attributable to the fact that complex economies like France produce more diverse products higher knowledge, skills and technogical expertise; therefore resulting to a reduction in energy-intensive production and eventually improving biodiversity conservation. Similarly, the findings also suggest that FD enhances biodiversity, the level of financial maturity of France's financial system and proactiveness of Banque de France in introducing various mechanism in promoting intensive investments in R&D, and eco-friendly ventures. Similarly, France have been at the for front of the "taxonomy regulation", which guides lending institutions to focus more on providing eco-friendly loans and investments. Vis-à-vis, this regulation focuses banks to reduce their loan portfolios for high polluting sectors; this transition may create an incentive for corporation to shift to green innovations. Furthermore, the environmental social and governance (ESG) classification and environmental disclosures, may induce firms to embrace less energy intensive ventures, thus improving biodiversity. The detrimental consequences of economic growth on biodiversity in France can be explained via the energy consumption channel. A surge in economic growth increase energy demand and when dirty energies are consumed various pressures are put in motion such as (Mining, infrastructure, transport, and burning of fossil fuels) these activities, directly impacts on ecosystems (Usman et al, 2022). The impacts arising from such activity's triggers rising temperatures and natural disasters which results in habitat losses and extinction of species. This study is constrained due to a shortage of data; thus, we limited the analysis from 1988 to 2018.This is the sole drawback encountered during the research. other studies can extend this research by using panel data to give a holistic view on the association NC, EC, GDP and FD on BD.

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