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Educational resource management projects through digital innovation: Data-driven insights into efficiency, resilience, and empirical modeling

Shamim Akhter[1], Zulkiflee Abdul-Samad[2*], Tribhuwan Kumar[3], Musarat Shaheen[4]

[1]INTI International University, Persiaran Perdana BBN, Putra Nilai,71800 Nilai, Negeri Sembilan, Malaysia.
[2]Department of Quantity Surveying Faculty of Built Environment University of Malaya, 50603 Kuala Lumpur, Malaysia.
[3]Prince Sattam bin Abdulaziz University, KSA.
[4]Bahauddin Zakariya University, Multan, Pakistan.

Corresponding author: Zulkiflee Abdul-Samad (*Email: zulkiflee1969@um.edu.my*)

Abstract

This study investigates the dynamic interactions between digital innovation, economic development, population growth, and foreign direct investment (FDI) in determining natural resource management effectiveness. As environmental and economic pressures intensify, understanding how digital innovation can enhance resilience, efficiency, and evidence-based decision-making in sustainable resource management becomes critically important. The research employs Quantile Autoregressive Distributed Lag (QARDL) modeling and wavelet coherence analysis to examine time series data spanning from 1991 to 2023. This methodological approach enables the identification of temporal and quantile-dependent interactions while revealing dynamic patterns of influence on natural resource management effectiveness across different time periods and variable distributions. Wavelet coherence analysis reveals increasing synchronization between digital innovation, foreign direct investment, and resource management efficiency since 2015, with correlations ranging from 0.8 to 1.0 across most time periods. QARDL estimates demonstrate stable long-term equilibrium among the studied variables, showing that digital technology and FDI contribute positively across quantiles, while population expansion consistently pressures resource efficiency. Economic development exhibits a dual role, enhancing short-term efficiency but generating adverse long-term effects. Education emerges as a pivotal factor that amplifies the positive impacts of digital innovation on sustainable resource management. The study establishes that digital innovation serves as a crucial driver for sustainable resource management effectiveness, particularly when supported by strategic foreign investment and educational development. The temporal analysis reveals evolving relationships between variables, with strengthening correlations in recent years indicating growing integration of digital solutions in resource management practices. Policymakers should prioritize investments in digital innovation, population management strategies, FDI-driven sustainability initiatives, and green capacity building to enhance natural resource efficiency, equity, and long-term environmental resilience. Education functions both as a beneficiary and driver of digital innovation, requiring integrated approaches that advance digital education alongside sustainability principles. Such strategies will empower future generations to address multidimensional challenges and lead transitions toward more efficient and equitable natural resource utilization through adaptive, time-sensitive policy interventions.

Keywords: Digital technology (DIGTECH), Educational gap, Natural resource management efficiency (NRME), Project, Resource efficiency, Sustainable development education.

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1. Introduction

Education plays a foundational role in addressing the challenges Denmark faces in the sustainable management of its natural resources. Given issues such as government neglect, unclear ownership, and insufficient market mechanisms, education can serve as a catalyst for improving both understanding and practice in resource governance and utilization. The sustainable development of an economy hinges on the pivotal role of natural resource assets. Effectively managing these resources is essential for economic progress and protecting national interests. Denmark faces natural resource shortages due to government neglect and management mismatches, complicating effective protection and utilization. Key issues include insufficient market utilization, unclear ownership, and inadequate property protection [1, 2]. Thus, analyzing natural resource management is crucial to improving operational efficiency and balancing multiple values associated with these resources [3-6].

Natural resource management involves coordination, planning, organizing, and controlling to maximize value and enhance well-being [7]. Scholars emphasize management institutions and subsystems, including theories of sustainable development, asset accounting, and management strategies [8-12].

The intersection of digitalization and sustainable development is gaining prominence in business transformation [13]. Bansal [14] highlights the urgent need for sustainable development amid business activities exceeding planetary limits. However, erosion of social institutions and digital technology convergence challenge sustainability progress. Industry 4.0 integrates digital technologies into industrial processes, aiming to transform production, sales, innovation, and foster a sustainable future [13, 15, 16].

Sustainable development propels economic advancement by harnessing scientific potential, green finance, and green economy strategies. Environmental disasters over the past two decades have driven global leaders to develop mitigation strategies [17, 18]. Attention to rare earth metals is rising due to their critical role in industries like electronics and manufacturing [19]. Prioritizing climate concerns, resource management efficiency, green initiatives, and digitalization demands economic reform to improve sustainability.

Recent focus on sustainable development and digital transformation highlights their interconnectedness. Rapid technological evolution and growing recognition of sustainability needs foster collaboration between these fields. This study is significant for addressing global challenges and advancing understanding of digital technology, natural resource management efficiency, and sustainable development, catalyzing positive transformation toward a resilient future.

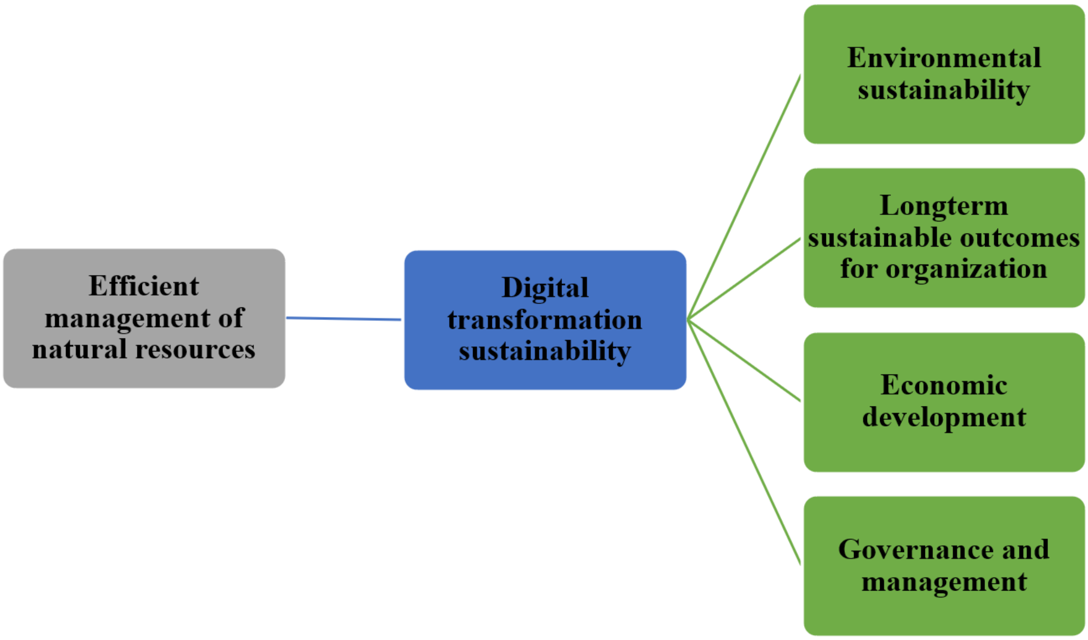

Figure 1.
Conceptual framework.

1.1. Objectives of The Study

1. To quantify the influence of digital technology on natural resource management efficiency.
1. To analyze the factors driving efficiency gains in natural resource management including environmental resilience and sustainability.
2. To provide empirical evidence through data analysis to support the relationship between natural resource management efficiency, digital technology, and sustainable development outcomes.
3. Using wavelet coherence analysis, to investigate the scale-dependent and temporal relationships between economic development, digital technology, FDI, and population growth in order to find dynamic patterns of influence on the effectiveness of natural resource management and assist in the creation of adaptive, time-sensitive policy interventions.

2. Literature Review

The rapid growth of the economy underscores the imperative for sustainable development. The backbone of sustainable development and a green economy rests on advanced technology, enabling the preservation of human habitat, catalyzing enduring economic progress, and encouraging sustainable utilization of energy and resources [20]. Innovation in scientific research incentivizes businesses and governmental entities to adopt prudent resource utilization, safeguard the environment, and reduce pollution, laying the ground for rapid and stable economic growth [21, 22]. The technological market and innovation are interconnected, serving as a hub for trading and circulation of technological commodities, bridging the gap between science, economy, and technology. Within this market, a dynamic interplay of scientific and technological breakthroughs fosters a symbiotic nexus between economy and technology, emphasizing cohesive collaboration and integration [23-26].

Wang, et al. [27] utilize Data Envelopment Analysis (DEA) to evaluate productivity and transformations in managing China's natural resources. The study reveals regional disparities in DEA effectiveness, with three provinces showing significant insufficiencies. Overlapping responsibilities, inadequate tax collection, and governmental priorities hinder industrial enterprises' participation in certain regions. The study recommends clarifying ownership, strengthening governmental commitment, and equitable tax distribution to facilitate environmental conservation and economic growth.

Koval, et al. [28] discuss Ukraine's irrational use of natural resources, impacting population efficiency, macroeconomic performance, and public health. Increased individual responsibility and values may improve the situation. The study emphasizes rational strategies for development and management to mitigate adverse risks, including overuse of chemicals in agriculture, ecological degradation, and inefficiencies in health sectors.

Di Vaio, et al. [29] explore the connection between AI, sustainable development, and machine learning, focusing on their potential to influence consumption and production patterns. A bibliometric analysis of English publications from 1990–2019 reveals innovation challenges across economic, ethical, legal, and social dimensions. This highlights the correlation between AI's development potential and the UN Agenda for Sustainable Development 2030 [30-32].

Economic efficiency analysis is crucial for benchmarking sustainability in commodities and industries, enabling the monitoring of economic and environmental sustainability amid rapid development and pollution. Chen, et al. [33] investigate how green technology impacts natural resource rent using panel data from the most populated states between 1990–2019. Findings suggest that economic complexity, green technology, natural resource rents, and financial development have positively influenced economic efficiency, while financial development has a negative impact in the most polluted states. The Dumitrescu and Hurlin causality test indicates a bidirectional association between financial development and economic efficiency, while green technology and resource rents show a unidirectional relationship. Advancements in renewable energy and environmentally friendly processing contribute to sustainable development and economic expansion [34-36].

Governments worldwide prioritize environmental protection, seeking policies that balance it with economic development [37]. Overuse of natural resources leads to severe environmental issues and climate change [38, 39] threatening long-term sustainable development goals [40, 41]. Despite international agreements, the worsening situation continues to capture expert interest in future environmental sustainability [42].

Economic efficiency, integrating social, economic, environmental, and resource considerations, is widely recognized as an indicator of sustainable development effectiveness [43]. Schaltegger and Sturm's concept merges ecological and environmental efficiency, enhancing productivity through efficient services or production using fewer resources and minimal environmental impact [44-46].

Natural resources like fossil fuels threaten environmental health [47]. While crucial for national income, human actions negatively influence the environment, diminishing productivity and water quality [48, 49]. This underscores the demand for technical innovation to drive economic growth and utilize abundant natural resources effectively [50, 51].

Digital technologies are revolutionizing manufacturing, offering opportunities for improved product development and efficiency but posing challenges for traditional production [52]. Technological advancements facilitate resource distribution efficiency, maximizing environmental sustainability [53-55]. However, new technologies may intensify business competition and impose monetary and ecological challenges [56]. The impact of digital technology on sustainable development remains underexplored [57]. Several empirical studies have examined digital technologies' influence on environmental sustainability via digital supply chain platforms [58, 59].

Green technology is increasingly important for reducing carbon emissions and enhancing innovation. Effective management and innovation are vital for environmental integrity and transitioning to a sustainable economy [60, 61]. However, green technology progression differs among nations, requiring comprehensive analysis in diverse socio-economic contexts [62-64].

Modernization of digital government plays a vital role in updating public administration, improving transparency, and fostering efficiency [65, 66]. Guan, et al. [66] investigate how digital government impacts natural resource rents across various economies. Their findings reveal that digital government increases natural resource rent, while external conflict leads to declines in Europe and America. Digitalization provides economic, social, and ecological benefits, fostering expansion and impacting market dynamics [67, 68]. Institutions managing natural resources are significant for channeling funds into profitable investments and ensuring resource efficiency and sustainable growth [69, 70]. The expansion of global economic activities has heightened the need for natural resources, causing scarcity and consumption concerns. Sustainable use is crucial for addressing developmental challenges, making sustainability a global concern [71]. Governments are seeking policy options that address resource stability and development goals, with digital technology potentially improving management efficiency [72]. Studies have examined the impact of digitalization on environmental quality, natural resources, economic growth, energy consumption, and tourism demand [73-76].

3. Empirical Aanalysis

3.1. Description of Model

The model given in Equation 1 offers insights into understanding natural resource management efficiency and various technological and socio-economic factors. The study is carried out using Quantile Regression within the context of Denmark`s landscape from 2000 to 2023. The study dataset originates exclusively from World Development Indicators [77].

$$NRME_t = POPGROWTH_t + DIGTECH_t + ECODEV_t + FDI_t + \varepsilon_o \quad (1)$$

Equation 1 focuses on natural resource management efficiency (NRME) followed by population growth (POPGROWTH), digital technology (DIGTECH), economic development (ECODEV), and foreign direct investment (FDI).

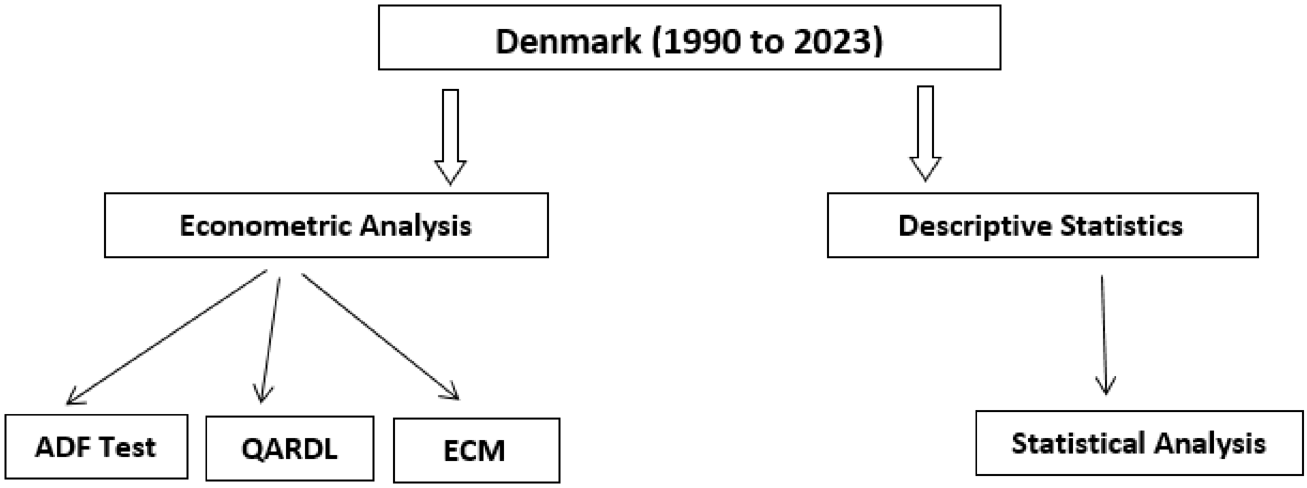

Figure 2.
Methodological Framework.

3.2. Estimation Technique

To comprehensively assess the intricate relationship between natural resource management efficiency and various technological and socio-economic factors across diverse quantiles, employing QARDL methodology [78-80]. This technique facilitates a nuanced exploration of interdependence among variables varying levels of criterion variables, capturing short-term and long-term dynamics. In addition, utilizing the QARDL framework and the Wald test to evaluate the consistency and stability of the parameters across different quantiles.

The standard or classic equation representing the ARDL model is as follows:

$$NRME_t = \gamma_o + \sum_{i=1}^{m} \gamma_{1i}\, \Delta POPGROWTH_{t-i} + \sum_{i=0}^{n} \gamma_{2i}\, \Delta DIGTECH_{t-i} + \sum_{i=1}^{p} \gamma_{3i}\, \Delta ECODEV_{t-i} + \sum_{i=0}^{Q} \gamma_{4i}\, FDI_{t-i} + \epsilon_t \quad (2)$$

Derived from the traditional ARDL framework, the QARDL model is expressed I Equation 3 [80].

$$QNRME_t = \gamma_{Ʈ} + \sum_{i=1}^{m} \gamma_{1i}\,(Ʈ)\Delta NRME_{t-i} + \sum_{i=0}^{n} \gamma_{2i}\,(Ʈ)\Delta POPGROWTH_{t-i} + \sum_{i=1}^{p} \gamma_{3i}\,(Ʈ)\Delta DIGTECH_{t-i} + \sum_{i=0}^{q} \gamma_{4i}\,(Ʈ)\Delta ECODEV_{t-i} + \sum_{i=1}^{r} \gamma_{5i}\,(Ʈ)\Delta FDI_{t-i} + \in_t (Ʈ) \quad (3)$$

Here, $\in_t$ (Ʈ)= $NRME_t$ -$QNRME_t$(Ʈ| t-1) and (0>Ʈ< 1) validate quantile [81] .

$$QNRME_t = \gamma_0 + \rho NRME_{t-1} + \gamma_{fPOPGROWTH} POPGROWTH_{t-1} + \gamma_{fdigtech} DIGTECH_{t-i} + \gamma_{fecodev} ECODEV_{t-i} + \gamma_{ffdi} FDI_{t-i} + \sum_{i=1}^{m-1} \gamma_{1i}\,(Ʈ)\Delta NRME_{t-i} + \sum_{i=0}^{n-1} \gamma_{2i}\,(Ʈ)\Delta POPGROWTH_{t-i} + \sum_{i=0}^{q-1} \gamma 3i\,(Ʈ)\Delta DIGTECH_{t-i} + \sum_{i=0}^{r-1} \gamma 4i\,(Ʈ)\Delta ECODEV_{t-i} + \sum_{i=0}^{p-1} \gamma 5i\,(Ʈ)\Delta FDI_{t-i} + \in_t (Ʈ) \quad (4)$$

Additionally, acknowledging the potential for serial correlation among the residual, the extended QARDL model is depicted in Equation 5.

$$QNRME_t = \gamma_0 + \rho NRME_{t-1} + \gamma_{fPOPGROWTH} POPGROWTH_{t-1} + \gamma_{fdigtech} DIGTECH_{t-i} + \gamma_{fecodev} ECODEV_{t-i} + \gamma_{ffdi} FDI_{t-i} + \sum_{i=1}^{m-1} \gamma_{1i}\,(Ʈ)\Delta NRME_{t-i} + \sum_{i=0}^{n-1} \gamma_{2i}\,(Ʈ)\Delta POPGROWTH_{t-i} + \sum_{i=0}^{q-1} \gamma 3i\,(Ʈ)\Delta DIGTECH_{t-i} + \sum_{i=0}^{r-1} \gamma 4i\,(Ʈ)\Delta ECODEV_{t-i} + \sum_{i=0}^{p-1} \gamma 5i\,(Ʈ)\Delta FDI_{t-i} + \in_t (Ʈ) \quad (5)$$

Moreover, long-run factors for natural resource management efficiency, digital technology, and sustainable development are calculated as

NRME*=$\frac{\gamma^{NRME}}{\rho}$;ɣPOPGROWTH*$\frac{\gamma^{POPGROWTH}}{\rho}$;ɣDIGTECH*$\frac{\gamma^{DIGTECH}}{\rho}$;ɣECODE$\frac{\gamma^{ECODEV}}{\rho}$;ɣFDI$\frac{\gamma^{FDI}}{\rho}$

ECM is expected to have a statistically negative influence [82].

3.3. Descriptive Statistics

The descriptive analysis provides valuable insights into the chosen variable (POPGROWTH, TNRR, DIGTECH, ECODEV, and FDI) for the present analysis.

Table 1.
Descriptive Statistics.

	POPGROWTH	NRME	DIGITECH	ECODEV	FDI
Mean	5492399.	0.847467	63.0.0926945	1.816454	2.393352
Median	5449355.	0.549607	85.02500	1.973272	1.402393
Maximum	5924484.	2.107733	104.0790	6.844522	21.93809
Minimum	5140939.	0.155033	0.097277	-4.906548	-4.997670
Std. Dev.	236516.6	0.565025	39.33959	2.052105	4.522231
Skewness	0.276045	0.555636	-0.670523	-0.748791	2.385933
Kurtosis	1.901397	1.986711	1.711745	5.746614	11.63465
Jarque-Bera	2.141620	3.204045	4.898843	13.86441	137.8811
Probability	0.342731	0.201489	0.086344	0.000976	0.000000
Sum	1.87E+08	28.81389	2151.161	61.75943	81.37398
Sum Sq. Dev.	1.85E+12	10.53534	51070.90	138.9675	674.8689
Observations	34	34	34	34	34

NRME symbolizes natural resource management efficiency with a mean of 0.847467, with a standard deviation of 0.565025. Next, evaluating POPGROWTH, the mean value is 5492399. Moving towards DIGTECH, the mean value is 63.26945, with maximum and minimum values of 104.0 and 0.09. Moreover, the distribution shows negative skewness (-0.671), indicating a longer left tail, and moderate Kurtosis of 1.71, suggesting a slightly less peaked distribution than normal. In addition, ECODEV, reveals a mean of 1.816454 with a standard deviation of 2.051. Moreover, the summary provides a detailed analysis of each variable`s variability, central tendency, normality, kurtosis, and skewness. Hence, providing insights into the respective analysis.

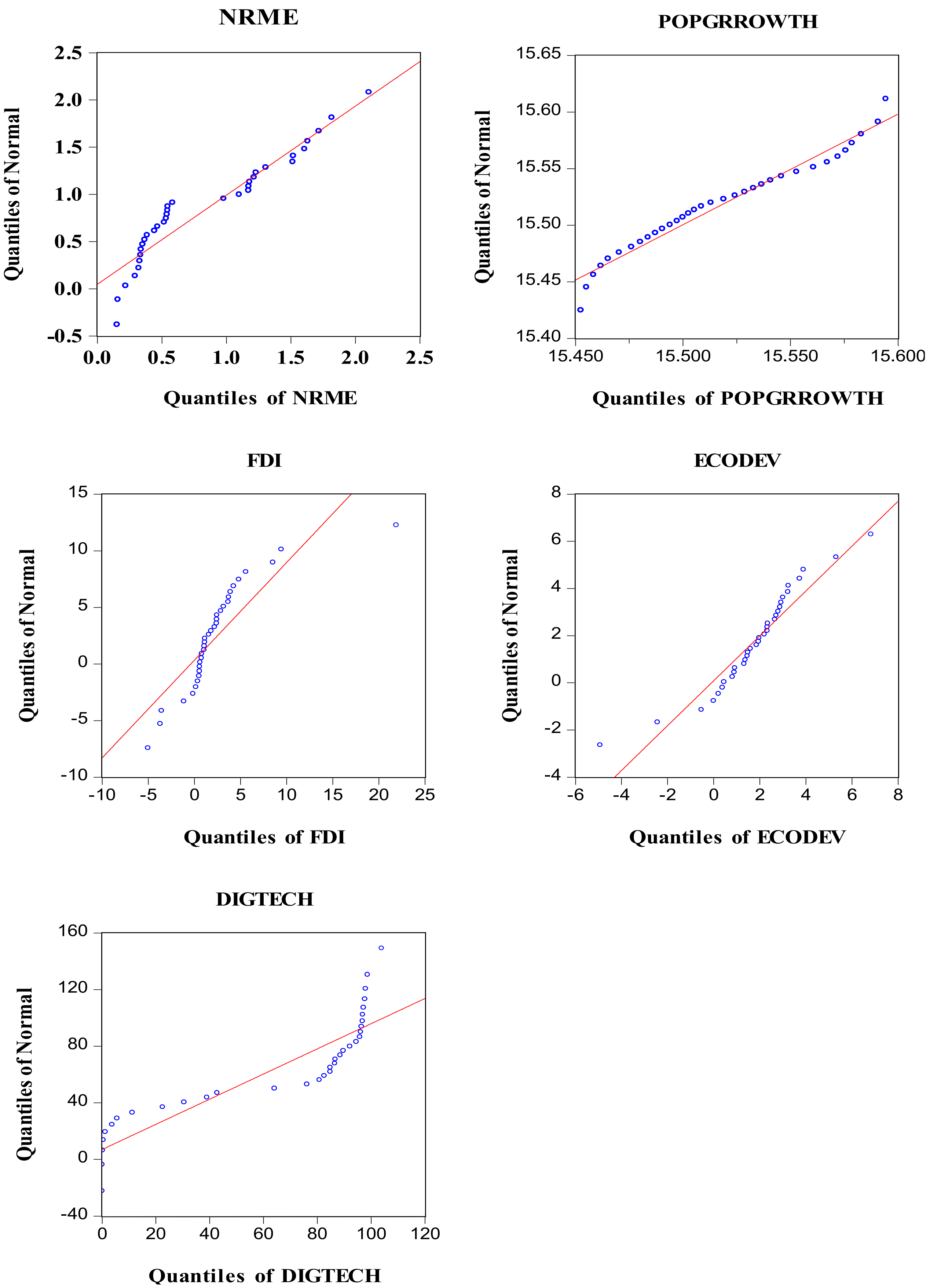

Figure 3.
Quantile data distribution.

3.4. Situational Analysis

In Denmark, the percentages represent the allocation of spending across various sectors of sustainable development as a proportion of GDP in 2022 (Figure 2).Denmark invested 80.60% in employment growth, followed by government expenditures (53.48%), infrastructure (49%), health (9.50%), spending on education (6.0%), and public order and safety (1.70).Denmark's commitment to sustainable development is evident in its significant investment in education, healthcare, infrastructure, and employment growth.

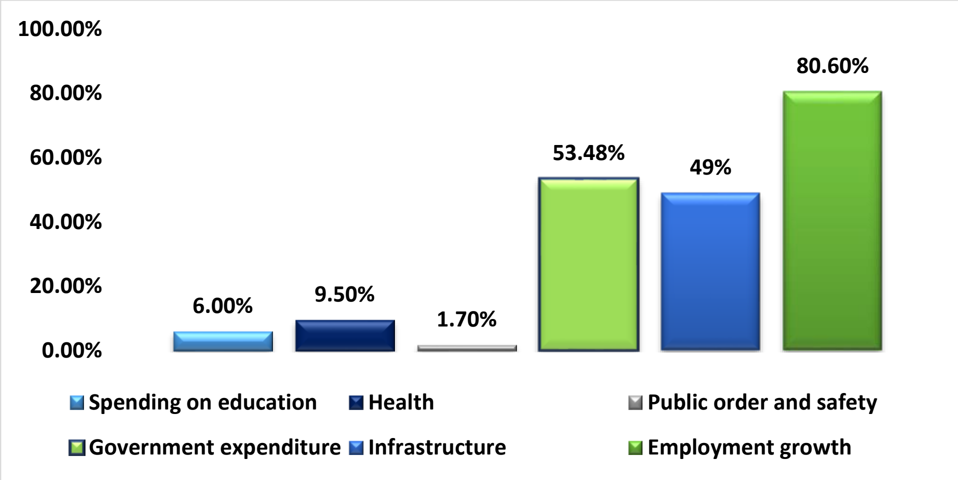

Figure 4.
Sustainable Development Sectors.
Data Source: WDI, Statista.

The Figure 5 shows the worldwide leading countries based on natural resource value. In 2021, Russia emerged as a global leader in natural resource value with a score of 75 followed by the United States with a score of 45. Saudi Arabia secured 3rd position with a score of 34.4 mainly due to vast oil and timber reserves. Similarly, Canada, Iran, and China also showcase their wealth in uranium, phosphate, oil, rare earth metals, and coal. Moreover, Brazil, Venezuela, Iraq, and Australia are among the countries with significant natural resources wealth, while India with its diverse resources like coal, natural gas, and diamonds has a lower score of 0.11.

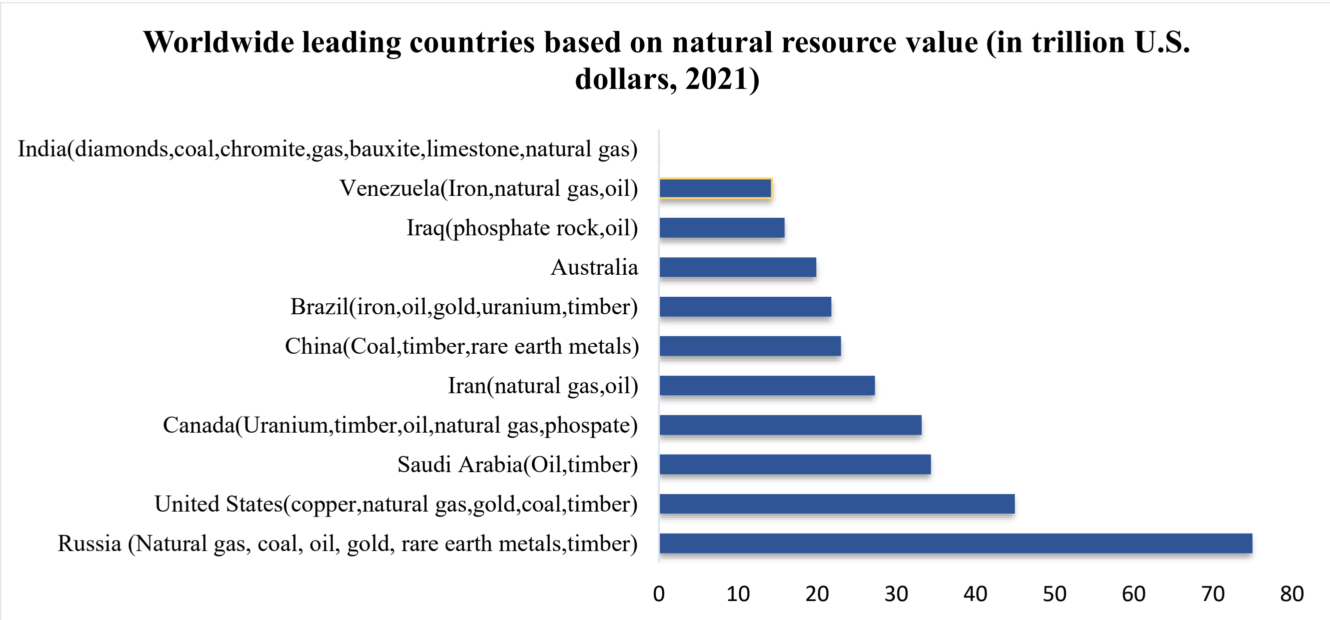

Figure 5.
Countries Natural Resource Value (Data Source :Statista).

3.5. Wavelet Coherence Analysis

This study relies on Wavelet Coherence (WTC) analysis to find dynamic, time and frequency based relationships between the efficacy of natural resource management and significant variables like digital technology (digtech), population growth (popgrowth), economic development (ecodev), and foreign direct investment (fdi). Unlike conventional static correlation techniques, WTC captures transitory patterns, lead-lag effects, and non-stationary trends, offering insights into how these variables interact over short- and long-term horizons.This method not only identifies periods of major effect, such the immediate impact of digital technology on resource efficiency, but it also supports empirical aims by showing when and how changes in investment or policy lead to durable outcomes. All things considered, WTC improves the analysis by enabling more accurate policy recommendations and more comprehensive, fact-based understanding.

4. Result and Discussion

4.1. Unit Root Test

Before employing the QARDL approach, it is crucial to confirm the order of integration of the model using the ADF test to determine the unit root test. In line with the study conducted by Liu, et al. [83], it is essential for all the variables utilized in the QARDL technique to exhibit integration either at level or at first difference. Findings of ADF results confirm that the model variable is integrated at the first difference, indicating the suitability of using the QARDL approach [84-86].

Table 2.
Augmented Dickey and Fuller Test.

Variables	Constant /Trend	Lags	T-stats(p-values)	Constant/ Trend	Lags	T-stats(P-values)	Remarks
NRME	C,T	1	-1.49 (0.81)	C, T	2	-5.55*** (0.00)	I(1)
POPGROWTH	C	1	1.100 (0.9)	C	1	-2.93** (0.05)	I(1)
FDI	C	1	-1.91 (0.45)	C	1	-3.34** (0.02)	I(1)
DIGTECH	C	1	-1.51 (0.51)	C	1	-3.07** (0.03)	I(1)
EODEV	C,T	1	-2.43 (0.36)	C,T	1	-5.08** (0.00)	I(1)

4.2. QARDL Short-Run and Long-Run Estimates

1. The QARDL findings in Table 3 show short-run results above and long-run below, highlighting significant error correction terms across quantiles, indicating sustainable equilibrium among population growth, foreign direct investment (FDI), digital technology, economic development, and natural resource management efficiency. Population growth negatively affects natural resource management efficiency in both upper (0.1) and lower (0.8) quantiles, consistent with previous studies [87-89]. It increases demand for resources like arable land, water, and forests, leading to depletion, land degradation, and habitat destruction, pressuring ecosystems and essential services [87, 90, 91]. FDI positively influences natural resource management efficiency in upper and lower quantiles [90, 92] .FDI supports efficiency through financial resources, technology, market access, and regulatory compliance, provided host countries align with sustainable development goals [93-95].
2. Digital technology also positively impacts natural resource management efficiency, with QARDL estimates showing positive relations across quantiles [17, 72, 96]. Technologies like GPS, remote sensing, and drones enable precise monitoring of environmental changes, water, and land use [21, 96]. Remote sensing is vital for characterizing agricultural resources and climatic variations [97]. Digital tools enhance ecosystem restoration projects by providing detailed monitoring and accelerating processes [98].
3. Economic development shows a positive short-run relationship with natural resource management efficiency by encouraging research and technology investment, improving management practices [99-101]. However, long-run estimates reveal a negative relationship, as economic development can lead to overexploitation, resource depletion, degradation, and reduced conservation incentives, undermining sustainable practices [96, 102-104]. QARDL Short-Run and Long-Run Estimates

Table 3.
QARDL Short Run and Long Run Estimates.

Q (Ʈ)	ECM β (Ʈ)	B (POPGROWTH)	β (FDI)	B (DIGTECH)	B (ECODEV)
Short run					
0.1	-0.35***	-7.10**	0.01***	0.022***	0.012***
0.2	-0.45***	-6.98**	0.019***	0.026***	0.023***
0.3	-0.55***	-6.94***	0.031***	0.019***	0.037***
0.4	-0.74***	-5.52***	0.030***	0.021***	0.027***
0.5	-0.75***	-5.48***	0.030***	0.022***	0.026***
0.6	-0.57***	-2.49***	0.030***	0.020***	0.021**
0.7	-0.69**	-1.22***	0.042**	0.039**	0.022**
0.8	-0.48	2.10**	0.041	0.034**	0.016**
Long run					
0.1	16.44***	-3.21***	0.00	0.01***	-0.02**
0.2	17.55***	-3.30***	0.00	0.02***	-0.03**
0.3	20.26***	-3.85***	0.04***	0.02***	-0.02**
0.4	21.31***	-4.04***	0.03***	0.02***	-0.02**
0.5	22.89***	-4.31***	0.03***	0.02***	-0.07**
0.6	21.31***	-4.04***	0.03***	0.02***	-0.02**
0.7	21.64***	-4.04***	0.03***	0.02***	-0.07**
0.8	23.44***	-4.34***	0.02	0.02***	-0.04

Note: *,**,*** indicate significance levels at 10%,5%, and 1%, with t-statistics and standard errors omitted to streamline the presentation.

The Wald test results, as presented in Table 4, indicate the rejection of the null hypothesis due to non-linear trends and inconsistencies in the adjustment parameters rate. Under the null hypothesis, parameters are assumed to be consistent, whereas the alternate hypothesis posits the opposite.

Table 4.
Short Run and Long Run Results.

Variables	Wald stat (P-value)
Short run	
γPOPGROWTH	-0.002*** : (0.00)
γFDI	0.02*** : (0.00)
γDIGTECH	0.01*** : (0.00)
γECODEV	0.02** : (0.01)
Long run	
γPOPGROWTH	-0.006*** : (0.00)
γFDI	0.02*** : (0.00)
γDIGTECH	-0.04** : (0.03)
γECODEV	0.02*** : (0.00)

Note: Steric indicates a level of significance at 1%,5%, and 10% respectively.

4.3. Wavelet Coherence Results

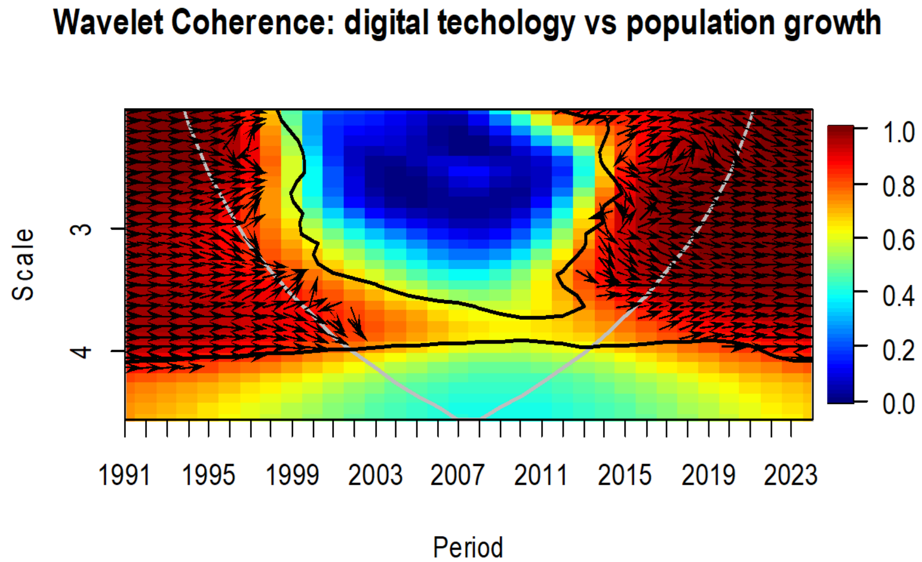

Figure 6.
Digital technology (DIGTECH) & population growth (POPGROWTH).

A dynamic and non-linear relationship between digital technology and population expansion from 1991 to 2023 is revealed by the wavelet coherence analysis, which is essential to comprehending effectiveness in sustainable resource management. The years 2004 to 2016 show low coherence, showing a divergence in their influence on resource efficiency, but the years before to 2002 and beyond 2018 show excellent in-phase coherence, indicating synchronized growth presumably due to integrated digital and demographic policies. In line with the study's goal of identifying efficiency drivers, the phase arrows' orientation emphasizes lead-lag impacts, where digital technology occasionally drives population-driven changes. The study's objectives of identifying empirical insights and simulating the changing effects of digital innovation on resource sustainability are directly supported by these temporal trends, which highlight the necessity of flexible, data-driven forecasting models and robust policy planning.

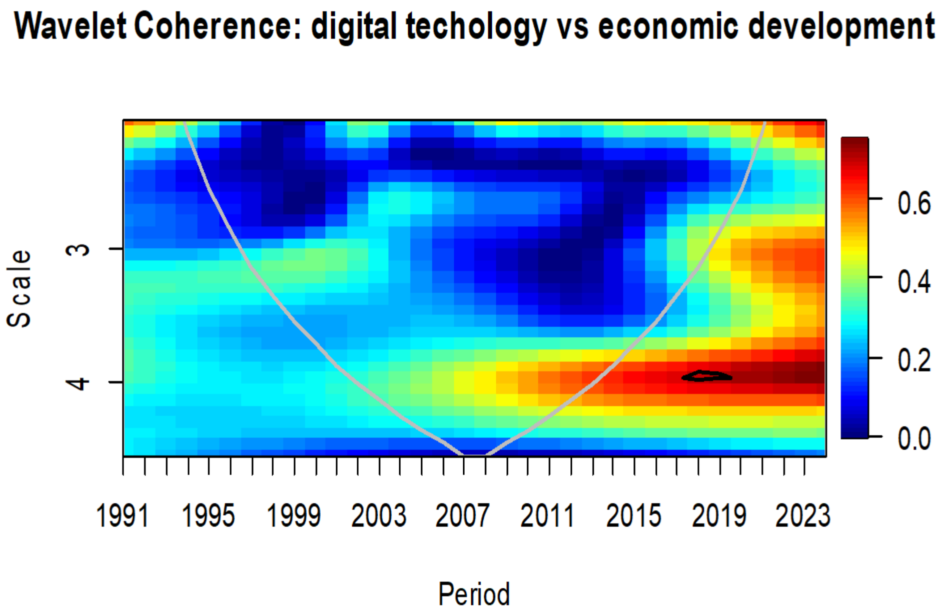

Figure 7.
Digital technology (DIGTECH) & economic development (ECODEV).

The wavelet coherence chart, which examines the relationship between economic development and digital technology from 1991 to 2023, shows a generally weak and erratic correlation over time. Only after 2018 does a notable coherence emerge, especially at larger time scales (scale ~4) around 2020–2023. This pattern indicates that although economic development and digital technology were mainly separated for the majority of the observed period, there has been a strengthening of the relationship in recent years, most likely as a result of policy changes and technological integration that has accelerated the digital transformation of economic systems. The delayed but increasing coherence suggests that long-term economic trajectories may be beginning to be shaped more significantly by digital innovation. The importance of integrating temporal dynamics into predictive modeling and policy design aimed at enhancing resource efficiency and economic resilience is highlighted by this finding, which empirically highlights a time-dependent relationship between digital innovation and sustainable development.

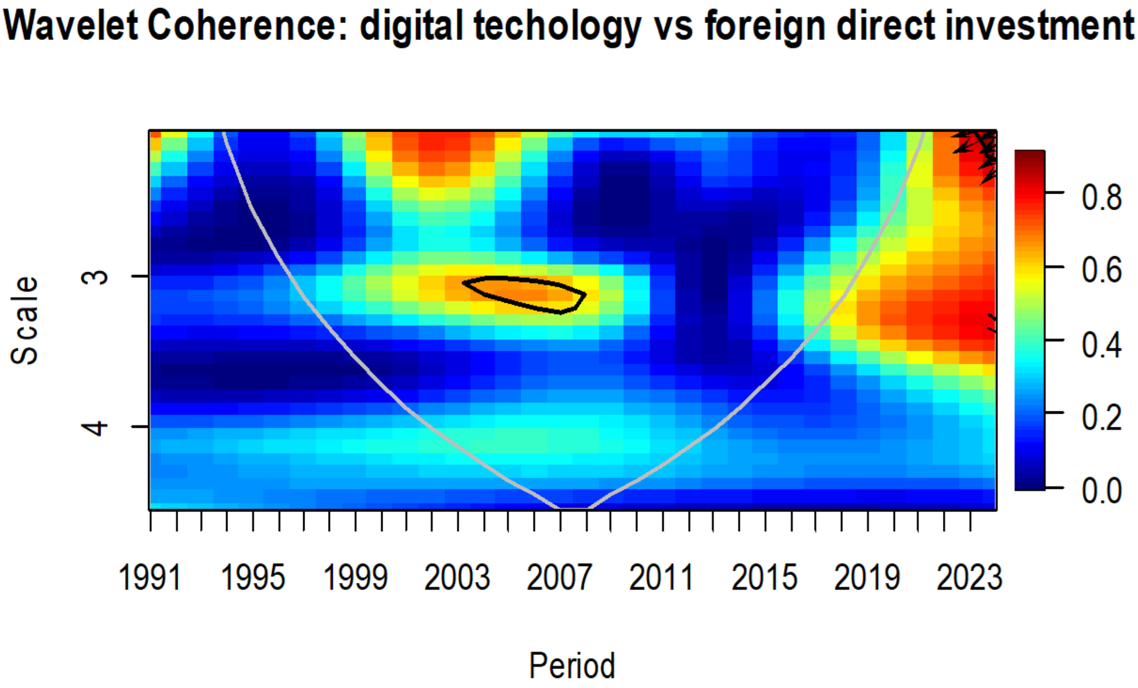

Figure 8
Digital technology (DIGTECH) & foreign direct investment (FDI).

A notable localized coherence zone about 2004–2008 at scale 3 is highlighted in the wavelet coherence chart between digital technology and foreign direct investment (FDI) from 1991 to 2023. This indicates a medium-term, time-specific correlation where the two variables moved in unison. This implies that, in line with worldwide trends of tech-driven investment flows, FDI may have helped advance digital infrastructure during that time or vice versa. The association seems weak or erratic outside of this frame, especially in the post-2010 era when coherence is still low, suggesting that FDI and digital innovation have not been consistently aligned.This finding is consistent with the study's goal of identifying factual, time-sensitive relationships that affect sustainable development and the effectiveness of resource management. The existence of discrete high-coherence periods highlights the value of predictive modeling and adaptive policy frameworks, which take into consideration the intermittent but significant role of external capital in influencing digital transformation and, eventually, sustainable resource outcomes.

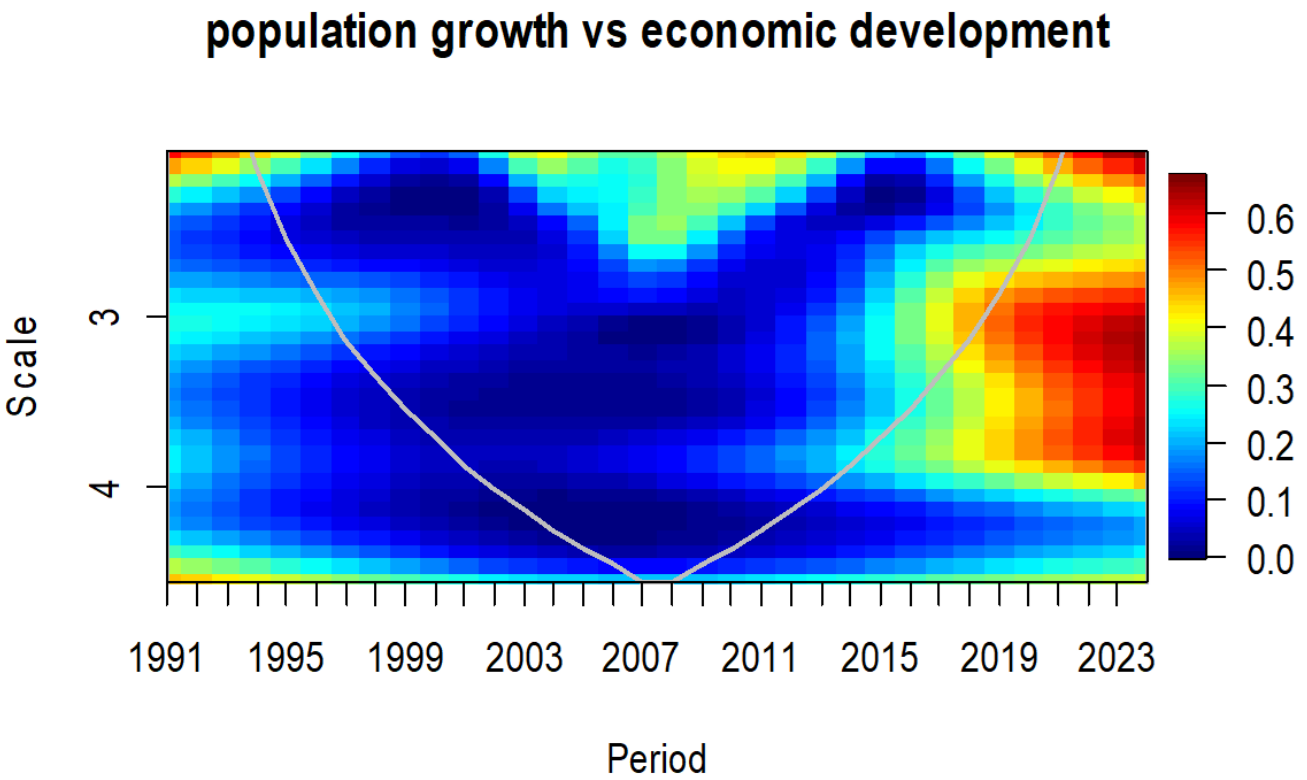

Figure 9.
Population growth (POPGROWTH) & economic development (ECODEV).

A notable localized coherence zone about 2004–2008 at scale 3 is highlighted in the wavelet coherence chart between digital technology and foreign direct investment (FDI) from 1991 to 2023. This indicates a medium-term, time-specific correlation where the two variables moved in unison. This implies that, in line with worldwide trends of tech-driven investment flows, FDI may have helped advance digital infrastructure during that time or vice versa.The association seems weak or erratic outside of this frame, especially in the post-2010 era when coherence is still low, suggesting that FDI and digital innovation have not been consistently aligned. This finding is consistent with the study's goal of identifying factual, time-sensitive relationships that affect sustainable development and the effectiveness of resource management.

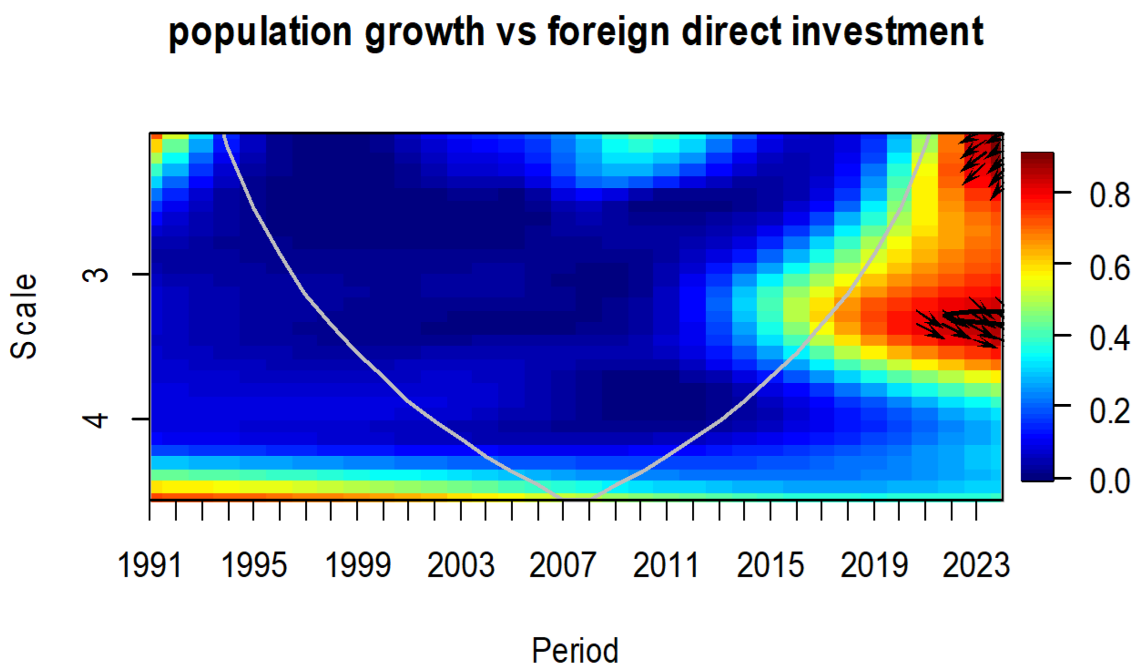

Figure 10.
Population growth (POPGROWTH) & foreign direct investment (FDI).

The dynamic and time-localized relationship between population growth and foreign direct investment (FDI) from 1991 to 2023 is depicted in the wavelet coherence plot. This graphics are used as a stand-in to comprehend how external economic investments possibly fueled by digital infrastructure and innovation align with demographic pressures over time. The significant coherence shown after 2015 points to a growing synchronization between investment flows and population dynamics, which may be a result of digital technology' increased importance in maximizing the management of natural resources and drawing in specific foreign direct investment. This pattern might point to increased sustainability and efficiency, which would be consistent with digital innovation. Significant influence is reflected in the color intensity (red to yellow) throughout this phase, which supports the goal of empirically examining the factors that influence the effectiveness of natural resource management. Finding these temporal tendencies also makes it easier to forecast future resource efficiency using predictive models like adaptive boosting, providing a strong foundation for resilient and sustainable policy design.

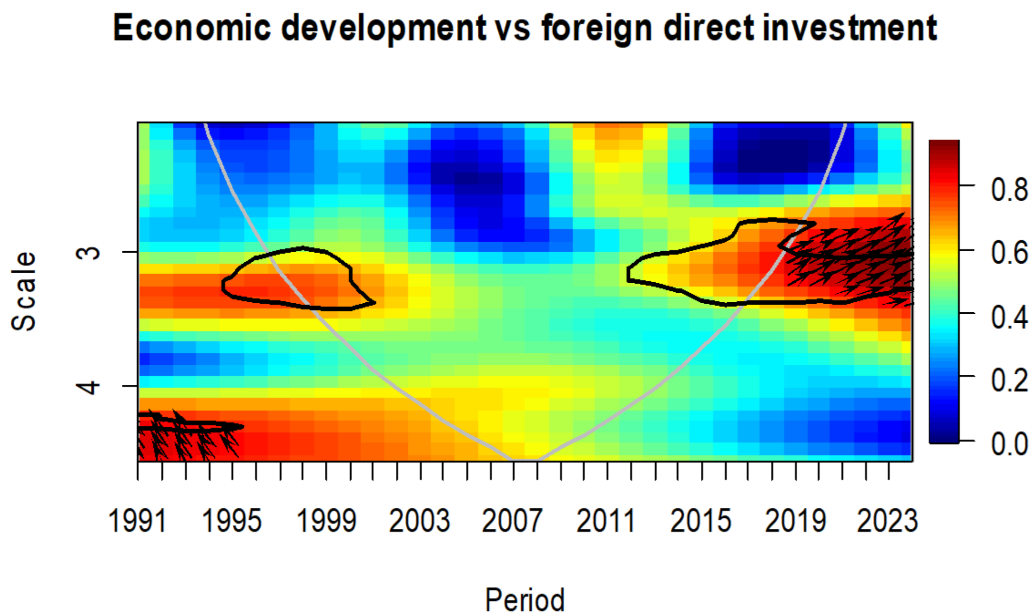

Figure 11.
Economic development (ECODEV) & foreign direct investment (FDI).

The theme "Harnessing Digital Innovation for Sustainable Resource Management" and its goals are well-aligned with the time-varying patterns of dependency revealed by the wavelet coherence plot of economic development vs foreign direct investment (FDI). Significant coherence zones during 1995–1998 and 2016–2022 point to times when FDI and economic development were closely related, maybe as a result of better policy frameworks and technology developments. Notably, the latter time frame aligns with the faster uptake of digital tools and resource management decisions that are informed by data.The in-phase relationship implied by the phase arrows in these regions, which primarily point to the right, suggests that increases in FDI are probably linked to increases in economic development, underscoring the mutually reinforcing influence of external investment and digital innovation on national growth strategies. These trends support the second and third objectives: identifying drivers of efficiency (such as digital infrastructure and sustainability policies) and providing empirical justification for the role of digital transformation in increasing natural resource management outcomes.

5. Conclusion and Policy Implications

5.1. Conclusion

Education plays a critical role in understanding and addressing the complex dynamics revealed by the QARDL estimations and wavelet coherence analyses in sustainable natural resource management.

The QARDL estimations provide empirical support for the study's objectives, confirming a stable long-term equilibrium among population growth, foreign direct investment (FDI), digital technology, economic development, and natural resource management efficiency. Population growth negatively impacts efficiency, especially in extreme quantiles, highlighting significant challenges for sustainable resource management. In contrast, digital technology and FDI positively influence resource management by enhancing monitoring, responsiveness, and adaptation through advanced tools such as remote sensing and GIS.

Wavelet coherence analyses reveal complex, time-varying relationships among these factors, with strong coherence observed since 2015, indicating an increasing alignment between strategic resource governance and digital innovation. These findings underscore the non-linear nature of digital transformation, shaped by temporal changes and external capital flows, and support the need for forward-looking policy frameworks to achieve long-term sustainability and effective management of natural resources. education is essential for building the knowledge, skills, and adaptive capacity necessary to interpret complex empirical analyses and to translate these insights into effective, sustainable resource management practices in a digitally transforming world.

5.2. Policy Implications

- Policymakers should prioritize investment in research and development for optimizing efficiency of natural resource management through digital innovations. This includes remote sensing technologies, and data tools related to analytics and digital platforms, enhancing efficiency, transparency, and accountability in resource management practices.
- Given the adverse effect of population growth on natural resource management efficiency. Policymakers should focus on population management strategies aimed at promoting sustainable demographic trends. This may include investment in educational campaigns on reproductive health, family planning, and endeavors to empower women by providing access to economic and education opportunities.
- To attain sustainability objectives, government should promote sustainability by attracting FDI through incentives, environmental impact assessment, and supply chain advocacy. Fostering collaborative connections between local communities and foreign investors is crucial for equitable resource distribution and long-term environmental preservation.
- It is essential for policymakers that they should prioritize green innovation and capacity building to heighten resource efficiency and environmental sustainability.

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