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The potency of resource efficiency and environmental technologies in carbon neutrality target for Finland

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ABSTRACT

Motivated by Finland's ambitious transition to circular economy through the reduction of consumable non-renewable resources and carbon neutral 2035, this study employs the Fourier approaches of stationarity, cointegration, causality alongside the long-run estimators of fully modified and dynamic least squares to examine the environmental aspects of resource productivity, environmental-related technologies, and export intensity over the period 1990–2020. Interestingly, given the two long-run estimators, the result established that a percent increase in raw material productivity yields a decline in greenhouse gas emission by a range of 61–70 percent. Additionally, there is a desirable and statistically significant impact of environmental-related technologies on greenhouse gas emission with an elasticity range of 0.16–0.18 in the long-run. While the intensity of export activities does not constitute a significant impact, economic growth as measured by Gross Domestic product (GDP) significantly hampers environmental sustainability in the long-run. Moreover, the causality approach including the Fourier Toda Yamamoto offers a strong inference along the insinuation of the long-run results for all the examined factors. Given this observation, relevant policy measures were highlighted to further guide decision makers in Finland on the pursuit of circular economy and carbon zero target.

1. Introduction

Given the Finland's target for carbon neutrality by 2035, the country has some of the world's most stringent environmental policies and ambitious climate targets. For instance, Finland's recent (precisely on 7th April 2021) adoption of the resolution on promoting a circular economy both targets the reduction of consumable non-renewable resources and restriction of renewable natural resources utilization (Ministry of the Environment, 2021). Specifically, as reported by Finland's Ministry of the Environment (2021), the country's resolution targets carbon-neutral circular economy society by 2035 such that both resource efficiency i.e material productivity and circular material use rate (CMU) are expectedly doubled by 2035. Despite the aforementioned resolution, the direct input of natural resources reportedly increased to the pre-coronavirus pandemic period due to the increase in soil materials and minerals which jointly constitutes 63 percent share of the total input natural resources[1] (Statistics Finland, 2021). As reported by the Statistics Finland (2021), Finland consumed 184 million tonnes of domestic natural resources in 2020, an equivalent of 193 million tonnes of domestic material utilization in the same year, thus corresponding to ~ 5 percent increase beyond the 2019 level.

Like the resource efficiency policy, neither technology nor environmental-related technologies alone are sufficient instruments for tackling climate crisis. Thus, environmental-related technologies could play a significant role in complementing policy instrument that offers resource efficiency. For instance, textiles and other sustainable and biodegradable products which are produced with biomass-related inputs could be sustainably manufactured by adopting technologically innovative methods. Thus, as a scalable and credible alternative to unconventional fuels, (energy) technology innovation such as Carbon capture and storage (CCS) technologies and digital mineral processing solutions are by far Finland's potential policy instruments to drive its carbon neutral 2035 given that the country is a global leader in Cleantech and smart grid technology. With Finland hosting approximately 3000

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[1] Finland's input natural resources mainly comprise of soil materials, minerals, wood, plants and wild animals, and manufactured imports.

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companies that are within the environmental technologies sector, a significant part of this number is operationally focusing on waste management, recycling, and resource re-use aspects of the economy (International Trade Administration, 2020). The essence, as supported by the recent work of Hosseinian et al. (2021), is that achieving a sustainable circular economy entails more deployment of innovations and new technologies.

In the context of the above motivation, and driven by Finland's ambitious carbon neutral 2035 goal, the objective of the study is to unearth the response of greenhouse gas emission to Finland's progress in material productivity efficiency and environmental technologies. Toward achieving the study's outlined goal, the Fourier-based econometric approaches that include the stationarity, cointegration, and Toda Yamamoto test types (i.e Fourier augmented Dickey–Fuller, Fourier-augmented Dickey–Fuller cointegration, and Fourier-Toda Yamamoto respectively) were applied alongside the fully-modified and dynamics ordinary least square method in order to provide the long-run evidence of the impact of material productivity efficiency and environmental technologies in GHG emission reduction in Finland. Generally, limited studies have been carried out about the drivers of environmental sustainability for the case of Finland and/or the Nordic countries (Alola and Nwulu, 2022; Alola and Onifade, 2022).). However, this is a rare study in the literature because it considers the key and evolving environmental (GHG emission) and circular economy (resource efficiency) aspects of Finland, thus making a significant contribution to the extant literature.

The remainder of this article is organized as follows: a synopsis of related literature review is presented in section 2 while the data and the empirical methods of the study are carefully presented in section 3. In section 4, we discuss the findings of the study. Finally, the summarized information about the study and the recommended policy relevance are presented in the last section 5.

2. Related literature: A synopsis

In the literature, especially with the 21st century research exploits, environmental-related technologies/innovation and efficient use of materials for economic output are increasingly linked as drivers of GHG emissions (Barrett and Scott, 2012; Hatfield-Dodds et al., 2017; Li et al., 2020; Plank et al., 2021; Onifade and Alola, 2022; Usman et al., 2022).

2.1. Environmental aspect of resource efficiency

For instance, the earlier study of Barrett and Scott (2012) employed the material flow analyses (MFA) to demonstrate the relationship between climate change and dematerialization i.e resource efficiency for the United Kingdom. By employing the extended input–output (EEIO) approach in an experimental pattern that understudy the production and consumption systems, the study provides analysis of the range of material efficiency aspects of GHG. Considering that the study offers measure to reduce GHG emissions in the UK by 2050, the result revealed that strategies for the consumption side of resource efficiency have the potency of delivering larger savings than production dynamics. Similarly, Hatfield-Dodds et al. (2017) equally provided resource efficiency projection for 2050 but by using multi-regional approach. Through the study's prediction, about USD $2.4 trillion through economic and environmental benefits could be realized by 2050 through efficient resource utilization while global resource extraction is further slowed by 28 percent by the target year (2050). In general, Hatfield-Dodds et al. (2017) opined that global emission by 2050 is expected to decline by 63 percent (below 2015 level) with the resource efficiency accounting for 15–20 percent decline in GHG emissions.

Furthermore, Plank et al. (2021) illustrated with the case of Austria to reveal the link between material efficiency utilization and carbon dioxide emission (CO_2) during the period 2000–2015. With an input-output approach, the study employed the consumption-based sectoral index decomposition analysis for a multi-regional basis. Given the interesting result, Plank et al. (2021) established that the current material efficiency policy in Austria appears to exhibit an inherent risk that could trigger emissions, thus projecting limited opportunities for decline in carbon emission and material utilization. However, the study revealed that the country's service industry through improvement in material efficiency posits a greater chance of carbon emission mitigation but that is not without the setback portend by economic growth. Meanwhile, the specific case of energy efficiency as a component of resource efficiency was linked with CO_2 for the sampled cases of China and Nigeria over the 1991–2014 in the study of Li et al. (2020). The study derived the energy efficiency from the energy intensity of the extractive and mining sectors through the use Fisher ideal index decomposition while using the panel-corrected standard error, autoregressive distributed lag, feasible generalized least squares, and Bayesian variance autoregressive approaches. By using the aforementioned econometric tools, the study failed to establish that energy efficiency in the two examined sectors and for the countries is good enough to provide policy tool for both circular economy and CO_2 reduction.

2.2. Environmental aspect of environmental technologies

In term of environmental-related technologies, Onifade and Alola (2022) examined the role of environmental-related technologies in driving the carbon neutrality 2050 drive of world's leading economies (Brazil, China, India, Indonesia, Mexico, Russia, and Turkey) over the period 1992–2018. By employing relevant panel econometric approaches, the study found that environmental-related technologies mitigate carbon emission in the short- and long-run with respective elasticities of 0.33 and 0.17. Additionally, the findings further revealed that environmental-related technologies played a moderating role by reducing the environmentally damaging impact of primary energy use in the panel of the examined countries. Again, Ahmad and Zheng (2021) offered a similar perspective for the case of Brazil, Russia, India, China, and South Africa (BRICS) over the quarterly 1990Q1-2016Q4 by using asymmetrical framework. The result of the investigation revealed different observations for positive and negative shocks in innovation in environmental-related technologies for the panel examination. Specifically, the findings established that a positive shock causes a decline in carbon emission i.e improve environmental quality while a negative shock yields an opposite result. In comparison, the impact of the positive shock in innovation in environmental-related technologies is found to be larger than the impact of negative shock.

Although the GHG-related emissions have been linked with environmental-related technologies and resource efficiency in the extant literature, however, export intensity has been rarely linked with GHG-related emissions. In this study, the addition of this perspective is an obvious merit to the existing literature.

3. Data and methods

In this part, the variables under investigation are described in detail especially their respective measurements and sources. This is followed by a specified ordering of the empirical approaches, starting from stationarity and cointegration tests to coefficient estimation and causality investigation.

3.1. Data

The yearly data covering the period between 1990 and 2020 was used to assess the interrelationship between GHG emissions and the independent variables (raw material productivity for green growth (RMP), exports intensity (EI), economic growth (GDP) and environmental-related technologies (ERT)). This paper follows the modification of the earlier studies on the drivers of environmental degradation as contained in Dietz and Rosa (1997) and York et al. (2003). Considering the incorporation of material consumption in the above-mentioned environmental model (Alola et al., 2021), raw material productivity for green growth is now being employed in the current study, thus providing the following empirical expression:

$$GHG_t = \beta_0 + \beta_1 GDP_t + \beta_2 RMP_t + \beta_3 ERT_t + \beta_4 EI_t + \varepsilon_t \tag{1}$$

Variables utilized in this empirical investigation comprise GDP: the gross domestic product as a measure of economic expansion (in constant 2010 $US); GHG emissions (in thousand tonnes); raw material productivity for green growth (in USD/KG), EI (in Kg/USD) and EI (in % of Percentage of all technologies). The data for RMP and GDP are gathered from the Global material flow database, EI and GHG are obtained from the World Bank database and ERT is gathered from the OECD database. The study period (1990–2019) is based on the unavailability of data beyond 2019 for ERT. Table 1 presents a piece of precise information about the variables. Fig. 1 present the flow of analysis.

3.2. Methods

As previously stated, and illustrated in Fig. 1, the empirical methods begin with the appropriate stationarity test, cointegration, and to the long-run estimation and causality estimation.

3.2.1. Fourier augmented Dickey–Fuller (FADF) test

The structural shifts were introduced by Becker et al. (2006) to the KPSS test initiated by (Kwiatkowski et al., 1992) utilizing the (Gallant, 1981)'s Fourier functions, so that number, form and the time were not pre-arranged (Enders and Lee, 2012).) introduced the nonlinear functions of the DF unit root test.

$$\Delta y_t = \alpha(t) + \delta t + \vartheta y_{t-1} + \sum_{i=1}^{p} \beta_i y_{t-1} + \varepsilon_t \tag{2}$$

where the deterministic term which is a function of time is depicted by $\alpha(t)$, optimal lag length ascertained by SIC or AIC is shown by p. The ε_t represents the error term and the coefficients are illustrated by β_i and ϑ. To avert the issue of autocorrelation, delayed values of Δy_t are encompassed in the framework. The null hypothesis = 0 test is perturbing when the form of the deterministic term is unclear and the term is computed wrongly. This issue can be solved by incorporating Fourier functions in the deterministic term, as shown in Equation (3):

$$\alpha(t) = \alpha_0 + \sum_{k=1}^{n} y1k^{sin}\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} y2k^{cos}\left(\frac{2\pi kt}{T}\right) \tag{3}$$

Substituting Eqn (3) into Eqn (2) yields the Fourier ADF (FADF) test with cumulative frequencies

$$\Delta y_t = \alpha(t) + \delta t + \sum_{k=1}^{n} y1k^{sin}\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} y2k^{cos}\left(\frac{2\pi kt}{T}\right) + \sum_{i=1}^{p} \beta_i y_{t-1} + \vartheta y_{t-1} + \varepsilon_t \tag{4}$$

Where; n is the number of Fourier frequencies in Equation (4). The introduction of too many frequency components limits the level of freedom and leads to errors. Equation (5) shows the Fourier element for a single frequency to tackle this limitation.

$$\alpha(t) = \alpha_0 + y1^{sin}\left(\frac{2\pi kt}{T}\right) + y2^{cos}\left(\frac{2\pi kt}{T}\right) \tag{5}$$

The FADF unit root test with single frequency is generated by inserting Equation (5) into Equation (2) as shown in the following Equation (6):

$$\Delta y_t = \alpha(t) + \delta t + y1^{sin}\left(\frac{2\pi kt}{T}\right) + y2^{cos}\left(\frac{2\pi kt}{T}\right) + \sum_{i=1}^{p} \beta_i y_{t-1} + \vartheta y_{t-1} + \varepsilon_t \tag{6}$$

The null hypothesis = 0 is "there is a unit root". Only the Fourier frequency (k) and number of observations (T) affect the table crucial values in which the t-statistic is compared. It is discovered that the variable can be described as a stationary process if the t-statistic is higher than the table value generated by the simulation bootstrap of Monte Carlo.

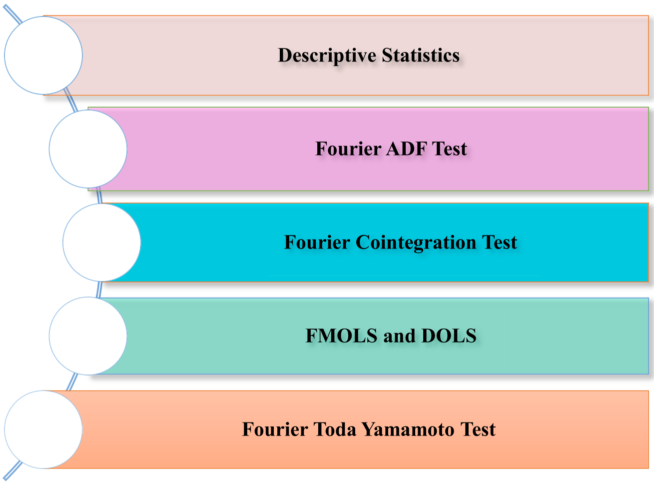

Fig. 1. Flow of analysis.

Table 1
Data source and measurement.

Variable Name	Sign	Measurement	Source
Raw material Productivity for green growth	RMP	USD/KG	Global Material Flows Database
Export intensity	EI	Kg/USD	World Bank Database
Greenhouse Gases Emissions	GHG	Thousand tonnes	World Bank Database
Economic growth	GDP	constant 2015 $US	Global material flow database
Environmental-related technologies	ERT	Percentage of all technologies	OECD Database

3.2.2. FADL cointegration

(Banerjee et al., 2017) introduced the FADL test which permits assessing the presence of cointegration by considering the break(s) with an unidentified time, number and structure. Utilizing (Gallant, 1981) Fourier function, they updated the conventional ADL test. There is no power loss owing to the use of several dummy variables in the FADL technique because structural breaks are recorded by a constant term (t). Another benefit is that when a small observation number is utilized, this technique can produce more effective outcomes than the VECM. The FADL test uses a single frequency Fourier approximation, which is stated as follows:

$$d(t) = \alpha_0 + \vartheta_1\ sin\left(\frac{2\pi kt}{T}\right) + \vartheta_2 co2\left(\frac{2\pi kt}{T}\right) \tag{7}$$

Where the specific frequency is depicted by k, the observations number is depicted by T, the trigonometric functions are cos and sin, and $\pi = 3.1416$. The FADL test can be demarcated as follows by integrating equation (7) to the conventional ADL technique:

$$\Delta y_t = \alpha_0 + \vartheta_1\ sin\left(\frac{2\pi kt}{T}\right) + \vartheta_2\ cos\left(\frac{2\pi kt}{T}\right) + \vartheta_3(y_{t-1} + \omega x_{t-1}) + \vartheta_4 + \sum_{i=1}^{q} \Delta y_{t-1} + \vartheta_5 \sum_{i=1}^{p} \Delta x_{t-i} + \varepsilon_t \tag{8}$$

It is believed that there is only one regressor in simplifying the description. The parameters are $\alpha_0, \vartheta_1, \vartheta_3, \vartheta_4$ *and* ϑ_5, specific lag length is depicted by i, the maximum enabled lag length are q and p, and the error term is depicted by ε_t. Furthermore, k is the optimal value which can be ascertained centered on the residuals squared residuals minimum value. The lag length optimal value can be described as per AIC and SIC smallest value. The Ho of "no cointegration ($\vartheta_3 = 0$)" is evaluated against the Ha hypothesis of "cointegration ($\vartheta_3 \neq 0$)". If the t-value of ϑ_3 ($t^F_{ADL}(\widehat{k})$) is less than the AIC values Ho of "no cointegration" is dismissed.

3.2.3. The Fourier causality test

The Toda and Yamamoto (1995) (now referred to as TY) causality test initiated by is extensively utilized since it permits evaluating series with various integration order. However, the TY causality test utilizing approximation of Fourier was further extended in the study of Nazlioglu et al. (2016). The approach does not necessitate any prior knowledge of cointegration and unit root features. The following equation can be utilized to execute this test, which is centered on the VAR (p + dmax) model.

$$y_t = \alpha + \delta_1 y_{t-1} + \ldots\ldots\ldots\delta_p + d_{max} y_{t-(p+d_{max})} + \varepsilon_t \tag{9}$$

(Nazlioglu et al., 2016) devised the FTY causality test by incorporating equation (7) in equation (9) to account for structural break(s) with an unspecified structure, date, and number. As a result, the consequences of smooth structural discontinuities in causal connection have been considered. Equation (6) can be utilized to simulate the single frequency FTY method.

$$y_t = \delta_0 + \delta_1 y_{t-1} + \ldots + \delta_{p+} d_{max} y_t - (p + d_{max}) + \vartheta_1 \, sin\left(\frac{2k\pi t}{T}\right) + \vartheta_2 \, cos\left(\frac{2k\pi t}{T}\right) + \varepsilon_t \tag{10}$$

Where y_t shows the vector comprising the variables of GHG, ERT, EI, RMP and GDP, the constant term is depicted by δ_0. The Fourier terms parameters are ϑ_1 and ϑ_2, the lag length of the VAR model is depicted by p, the maximum integration order is depicted by d_{max}, and error term is depicted by ε_t. The Ho hypothesis and Ha hypothesis are "non-causality" and "causality" respectively.

4. Findings and discussion

Table 2 presents brief statistical information on the data we used in this paper. The average value of GDP is 2.06E+11 and it ranges between 1.41E+11 and 2.56E+11, of GHG is 51218.84 and it falls between 35392.21 and 66860.79, of ERT is 11.520 and ranges from 4.050 to 21.90, of RMP is 1.0846 and ranges from 0.9533 to 1.257900, and of EI is 0.235787 with a range between 0.1538 and 0.3314. Furthermore, only ERT and RMP are skewed positively. Moreover, GDP, GHG, ERT, EI and RMP are platykurtic. In addition, all the variables affirm to linearity as disclosed by the Jarque-Bera. Moreover, Table 3 presents the ADF and FADF unit root test outcomes. These tests are conducted to assess whether GDP, GHG, ERT, EI and RMP are stationary for Finland. As a result, the goal is to evaluate the series' maximum order of integration. The outcomes from both FADF and ADF revealed that all the variables are $I(1)$ i.e. they are stationary at first difference.

Table 2
Descriptive statistics.

	GDP	GHG	ERT	EI	RMP
Mean	2.06E+11	51218.84	11.52000	0.235787	1.084600
Median	2.20E+11	53063.21	7.870000	0.243150	1.089400
Maximum	2.56E+11	66860.79	21.90000	0.331400	1.257900
Minimum	1.41E+11	35392.21	4.050000	0.153800	0.953300
Std. Dev.	3.86E+10	9123.767	6.243420	0.050883	0.083269
Skewness	−0.481534	−0.231094	0.601930	−0.027740	0.247613
Kurtosis	1.734231	1.772918	1.692201	1.727748	2.174862
Jarque-Bera	3.162091	2.149184	3.949522	2.027129	1.157628
Probability	0.205760	0.341437	0.138794	0.362923	0.560563

Table 3
Fourier ADF unit root test results.

Variables	ADF		FADF		
	I(0)	I(1)	I(0)	I(1)	k(p)
GHG	−2.0808	−6.0752*	−2.5343	−5.6663*	2(0)
GDP	−1.0678	−3.9382**	−3.2567	−6.6031*	1(3)
RMP	−2.2137	−5.5293*	−2.1246	−5.2183*	1(0)
ERT	−1.8395	−4.5512*	−2.5392	−4.6092**	2(0)
EI	−1.9574	−4.9318*	−3.0487	−8.1112*	1(0)

Note: ** and *depicts 5% and 1% level of significance.

4.1. Fourier cointegration result

Since the variables are I (1), we can employ the Fourier Autoregressive Distributed Lag (FADL) cointegration test. Thus, the long-run interrelationships in Finland among raw material Productivity for green growth, export intensity, GHG emissions, economic growth, and environmental-related technologies are scrutinized. Table 4 shows the FADL cointegration test outcomes and reveals that there is a connection between raw material Productivity for green growth, export intensity, GHG emissions, economic growth, and environmental-related technologies in the long-term. The statistics approve long-term cointegration relations. The long-term cointegration relationships are backed by the statistics. As a robustness check, we used the Bayer-Hanck Cointegration, and the result affirms the Fourier ADL cointegration test outcome (See Table 5).

4.2. Long-run relationship outcomes

Subsequently, the long-run estimators (FMOLS and DOLS) are employed to explain the effect of raw material productivity for green growth, export intensity, economic growth, and environmental-related technologies on GHG emissions (see Table 6). As revealed, there is a significant and positive connection between GDP and GHG emissions in Finland. This shows that ~1.3705% (for FMOLS) and ~1.3999% (for DOLS) upsurge in GHG emissions is caused by a 1% upsurge in GDP when other indicators are constantly held. Thus, it is evident based on the empirical findings that the economic growth of Finland is not environmentally sustainable.

Moreover, the effect of raw material productivity for green growth on GHG emissions is negative and significant. This infers that ~0.7004% (for FMOLS) and ~0.7004% (for DOLS) decrease in GHG emissions is caused by 1% upsurge in raw material productivity for green growth when other factors are held constant. Furthermore, environmental-related technologies impact GHG emissions negatively. Thus, holding other variables constant, 1% increase in environmental-related technologies decrease GHG emissions by 0.1779% (for FMOLS) and 0.1590 (for DOLS) respectively. Lastly, the effect of exports on GHG emissions is insignificant as disclosed by both FMOLS and DOLS estimators. The outcomes of the R^2 revealed that 80% ~ FMOLS and 81% ~ DOLS of the exogenous variables can explain GHG emissions.

4.3. Causality relationship outcomes

Lastly, the causal connection between GHG emissions and the independent variables was assessed using the novel fourier toda yamamoto (FTY) and toda yamamoto (TY) causality tests. Table 7 presents the FTY and TY test results. The results show that economic growth, environmental-related technologies, and raw material productivity for green growth Granger cause GHG emissions. Therefore, the null hypothesis is dismissed. Hence, economic growth, environmental-related

Table 4
FADL cointegration.

$F_{ADL}(k)^\wedge$	$(k)^\wedge$	AIC	Lags					Results
			ΔGHG	ΔGDP	ΔRMP	ΔERT	ΔEI	
4.683**	1	8.732	1	2	2	1	1	Cointegrated

Critical values for the Fourier ADL cointegration are −4.17, 4.51, and 5.17 at a significance level of 10%, 5%, and 1% respectively is gathered from (Banerjee et al., 2017).

Table 5
Bayer-Hanck cointegration test.

GHG = f(GDP, RMP, ERT, EI)	Fisher statistics	Fisher statistics
	EG-JOH 33.9741* Critical value 10.576	EG-JOH-BAN-BOS 54.0843* Critical value 20.143

Note: *depicts 1% level of significance.

technologies, and raw material productivity for green growth can predict GHG emissions. Furthermore, any shifts in these indicators, will substantially influence GHG emissions, therefore policymakers in Finland should consider these variables when formulating policies regarding GHG emissions.

4.4. Discussion of Findings

The study outcome shows that economic growth impact GHG emissions positively suggesting that the growth trend in Finland is not sustainable. The outcomes portrayed that an intensification in GDP has posed more challenges to GHG emissions controlling strategies as GDP has a significant and positive impact on GHG emissions. This is because the main economic activities (mainly industrial and manufacturing sectors) in Finland still rely on fossil fuel energy mix, thus continuing to cause environmental setback amidst economic expansion. Furthermore, Finland's reliance on coal for its economic activities is likely factor for this association. Therefore, policymakers in Finland should continue to uphold policies that will reduce reliance on coal consumption in Finland. This is seen in the GHG emissions per capita of Finland which is higher than top-emitting nations such as China, India, Japan, the USA and South Korea. This result louds the results from the studies of Ojekemi et al. (2022) on the drivers of GHG emissions for the BRICS countries. Furthermore, the research of Akadiri et al. (2022) for China between 1990 and 2018 documented similar results. However, this result contradicts the study of Usman et al. (2020) for the USA.

Moreover, we found that raw material productivity for green growth impact GHG emissions negatively. This implies that the utilization of raw material productivity for green curbs GHG emissions; thereby enhancing the quality of the environment. This is a critical road strategy for implementing sustainable development. As a result, it has the capacity to maintain both environmental sustainability and economic growth. As a result, raw material productivity for green growth has the capacity to affect these goals, as it has a negative impact on GHG emissions. It shows that Finland's attempt to curb GHG emissions is commendable. Specifically, the finding is a motivation for Finland to advance the implementation of appropriate strategies for reducing GHG emissions in the long run. GHG emissions can be reduced by implementing a green growth strategy that includes increasing renewable energy usage and raising environmental taxes while improving energy efficiency. This outcome complies with prior studies. For instance, the study of Dogan et al. (2022) on the connection between environmental deterioration and raw material productivity documented similar results. Similarly, the study for the case of China by Chien et al. (2021) reported that green growth enhances environmental integrity.

Additionally, as anticipated, the Environmental-related technologies coefficients in the model estimated indicate that an increase in Environmental-related technologies will lead to plummeting GHGs emissions. Environmental-related technologies in an advanced nation such as Finland are having eco-friendly effects concerning GHG emissions alleviation. This result is in line with He et al. (2021) for Mexico, which contends that environmental-related technology investments are among the schemes that can result in decreasing GHG emissions. Moreover, Oladipupo et al. (2021) explain that environmental-related technologies have eco-friendly effects on GHG emissions. This illustrates that the environmental-related technologies practically control the detrimental effect of GHG emissions in Finland during the study

Table 7
Causality outcomes.

	Fourier Toda Yamamoto				Toda Yamamoto		
	MWALD statistics	P-value	f	p	WALD statistics	P-value	p
$GHG \neq GDP$	2.1433	0.8431	1	1	1.6736	0.4958	1
$GDP \neq GHG$	17.5416***	0.0264	1	1	5.7405***	0.0978	1
$GHG \neq RMP$	2.6390	0.87674	1	3	1.4545	0.5278	1
$RMP \neq GHG$	31.700*	0.0000	1	3	6.0701***	0.0797	1
$GHG \neq ERT$	1.3705	0.7124	3	2	1.2740	0.3833	1
$ERT \neq GHG$	11.3604***	0.0953	3	2	6.1173***	0.0727	1
$GHG \neq EI$	1.5623	0.9715	1	2	2.4714	0.2906	2
$EI \neq GHG$	2.4914	0.8274	1	2	3.8497	0.1459	2

Note: ***, ** and *depicts 10%, 5% and 1% level of significance, f is the number of fourier, p is number of lag and P-value is the probability value.

Table 6
Long-run estimators (FMOLS and DOLS).

	FMOLS				DOLS			
	Coefficients	SE	T-statistics	P-value	Coefficients	SE	T-statistics	P-value
GDP	1.3705*	0.3568	3.8429	0.0009	1.3999*	0.3863	3.6564	0.0014
RMP	−0.7004**	0.2857	−2.4514	0.0231	−0.6122***	0.3386	−1.8077	0.0843
ERT	−0.1779**	0.0748	−2.3763	0.0271	−0.1590***	0.0900	−1.7658	0.0913
EI	0.1238	0.0975	1.2699	0.2180	0.1659	0.1176	1.4108	0.1723
R^2	0.80				0.81			
Adj R^2	0.79				0.80			
S.E. of regression	0.0952				0.0906			
Log Likelihood	0.0064				0.0093			

Note: ***, ** and *depicts 10%, 5% and 1% level of significance and SE, T-statistics, and P-value are the standard error, test statistics, and probability values respectively.

time-frame. According to Kirikkaleli and Adebayo (2021) there are myriad reasons why we can comprehend technological changes' significance in curbing environmental degradation, such as modifications in the energy mix; usage of efficient energy production technologies; and tend-of-pipe technology installation which is recognized as the most vital of the three. Similarly, Zhao et al. (2021) found that environmental-related technologies result in augmented energy efficiency and reduced intensity of energy, leading to lesser GHG emissions. Contrarily, this outcome failed to totally align with the line observation in the recent work of Lasisi et al. (2022) for the world's top performing eco-innovation states (Austria, Denmark, Finland, France, Germany, Netherland, Spain, and Sweden).

Lastly, the effect of export intensity is not significant which implies that export intensity does not contribute to an increase in GHG emissions; though it is positive. This suggests that policymakers in Finland should re-strategize their policies regarding export intensity in order to enhance the environmental quality. Moreover, with the exemption of export diversity, all the exogenous variables (raw material productivity for green growth, economic growth and environmental-related technologies) can forecast GHG emissions.

5. Conclusion and policy recommendation

The focus of this study is to address the role of dematerialization and environmental-related technologies alongside export intensity in driving the carbon neutrality goal of Finland. By employing the dataset covering the period 1990–2020, estimation types of Fourier approaches ofor stationarity, cointegration, and causality examination offers useful results that are relevant for policy inference.

Importantly, through the fully modified ordinary least squares and dynamic ordinary least squares, the long-run relationships were established. The investigation revealed that raw material productivity and environmental-related technologies promotes GHG emission mitigation, thus improving environmental sustainability. Although there is an inelastic impact of the aforementioned drivers of GHG emissions, both raw material productivity and environmental-related technologies are already justifying their effective role in Finland's carbon neutral 2035 agenda. Additionally, there is no evidence that economic growth is causing a decline of GHG emissions, rather GDP growth is responsible for increase in GHG emission at 1 percent statistically significant level. However, export intensity does not exert a statistically significant impact on GHG emissions as evident from the two estimators. Moreover, there is harmony in the causality evidence of both Fourier Toda Yamamoto and Toda Yamamoto such that shows causality from GDP, ERT, and RMP to GHG emissions. There is important policy inference from the result of the investigation.

The desirable evidence from the relationship between raw material productivity and GHG emissions further illustrates the capacity of circular economy advancement in Finland. Thus, the implementation of the country's circular economy policies should not only be encouraged but expanded to accommodate other relevant parts of socioeconomic activities. This approach should further strengthen the potential of a green value add from every sector of the economy. For the country's export activities, the components of the country's main exports should be further re-evaluated on the basis that it is not jeopardizing the nationally determined goal of sustainable environment at the detriment of economic growth. Moreover, the peculiarity of the above policy insight to Finland does not invalidate the relevance of the policy measures to the Nordic economies especially to Denmark, Norway, and Sweden. For instance, a policy change or modification to address the environmental demerit of export intensity could be advantageous (i.e encouraging local production) and disadvantageous (i.e., short-time spike in price arising from supply shortage) to the importing state.

Despite the relevance of the study, future study could be improved upon by investigating the sector performance of the country's environmental sustainability and even exploring the specifics of the country's export goods. Additionally, future study could explore the scenario of the panel of Nordic countries even in a comparative analysis.

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CRediT authorship contribution statement

Andrew Adewale Alola: Data curation, Conceptualization, Writing – original draft, Corresponding. **Tomiwa Sunday Adebayo:** Methodology, Investigation, Formal analysis.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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