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Assessment of sectoral greenhouse gas emission effects of biomass, fossil fuel, and (non)metallic ore utilization of the Nordic economy

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Abstract

In a rare empirical approach, and considering the uniqueness of the Nordic economy, this study examines the differential effect of domestic material utilization, i.e., biomass, fossil fuel, metallic ores, and non-metallic ores on the sectoral greenhouse gas (GHG) emission, i.e., industrial, agricultural, land use, land use change and forestry (LULCF), waste management, and energy GHG emissions in the period 1990–2020. By applying competent econometric tools that accounts for potential estimation bias, the result revealed that metallic ore consumption among the Nordic countries is detrimental to the region's environmental sustainability, more so to the region's greening circular economy drive. This is because metallic ore utilization spurs industrial, agricultural, LULCF, waste management, and energy GHG emissions. Similarly, biomass material consumption spurs GHG emissions arising from the LULCF, waste management, and energy sector activities while fossil fuel materials spur LULCF and energy GHG emissions. However, non-metallic ores consumption provides a desirable outcome as it mitigates GHG emission with respective elasticities of ~0.06, ~0.01, and ~0.05, in the industrial, agricultural, and waste management sector activities while biomass also plays a statistically significant role of reducing agricultural GHG emission by ~0.02% when there is a percent increase in the consumption of biomass. Important policy measures are put forward following the interesting revelation from the investigation.

Keywords Environmental sustainability · Ecological materials · Greening and circular economy · Nordic region

Abbreviations

AGHG	Agriculture GHG
AMG	Augmented mean group
CADF	Covariate Augmented Dickey-Fuller
CCEMG	Common correlated effect mean group
CD	Cross-sectional dependence
CIPS	Cross-sectionally augmented Im, Pesaran and Shin
CO_2	Carbon dioxide
DMC	Domestic material consumption
DMCB	Domestic material consumption (biomass)
DMCF	Domestic material consumption (fossil fuel)
DMCMO	Domestic material consumption (metal ores)
DMCNMO	Domestic material consumption (non-metal ores)
EGHG	Energy GHG
EE-IO	Environmentally extended input–output
EU	European Union
IGHG	Industrial GHG
GDP	Gross domestic product

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GHG	Greenhouse gas
HOMER	Hybrid optimization of multiple energy resources model
LULCF GHG	Land use, land use change and forestry GHG
LULCF	Land use, land use change and forestry
POP	Population
SDGs	Sustainable development goal
WGHG	Waste management GHG

Introduction

The Nordic countries are characterized by high domestic material utilization per capita especially with high utilization of fossil energy materials and non-metallic minerals in Norway, non-metallic minerals in Iceland, non-metallic minerals and biomass in Denmark, Finland, and Sweden (European Commission, 2021). However, the Nordic trio (Denmark, Norway, and Sweden) is among 24 economies that have reportedly managed to mitigate emissions from carbon dioxide (CO_2) and greenhouse gas (GHG) since 1970 (Lamb, 2022). Given the priority of the Nordic countries to further pursue a sustainable production and consumption, greening and circular economy as encouraged by the global goals of the United Nations Development Programme, policy proposals or enforcement measures have put forward these countries to support this agenda. For instance, the Nordic Working Group for Circular Economy (NCE) formulated a combination of priorities that is centered on reduction of resource consumption, non-toxic resources and waste-efficient cycle, green transition, and other resource-environmental-related measures. Specifically, in Denmark, Norway, and Sweden, the transformation toward attaining sustainable economy is being conceptualized as a policy in different approaches (Khan et al., 2021). Although the Nordic countries currently have high targets for GHG emission reduction in spite of the region's reliance on industrial export activities, the decades of structural transformations and economic growth are now more reliant on the policies of sustainable material-resources utilization.

Following the above perspective, the objective of the study is construed in the need to examine the role of each component of domestic material consumption (DMC), i.e., from biomass, fossil fuel, metallic ores, and non-metallic ores in disaggregated GHG emission. As highlighted above, the choice of the Nordic economies is not unconnected with the countries' unique profile in terms of the national ambitions to mitigate GHG emission and ensuring sustainable production and consumption among other sustainable development goals (SDGs)-related commitments. To achieve the central objective of the study, material consumptions in biomass, fossil fuel, metallic ores, and non-metallic ores are considered such that their long-run impacts on aggregated and disaggregated GHG emissions are investigated by employing set econometric techniques. Although these countries potentially share similar socioeconomic characteristics, more recently developed econometric tools that account for estimation bias are employed to have a robust outcome. Considering that there is a sparse literature that have examined the components of domestic material consumptions especially from the aspects of industrial, agricultural, land use, land use change and forestry (LULCF), waste management, and energy GHG emissions such as Alola and Adebayo (2023), the current study offers significant novelty while also highlighting key policy directives.

There are other parts of the study such as the discussion of related literature in the "Theoretical framework" section, highlight of the dataset and empirical methods in the "Data and methods" section, discussion of the results in the "Findings and discussions" section, and the concluding remarks with policy recommendation in the "Conclusion and policy recommendation" section.

Theoretical framework

Following the initial investigation by Holdren and Ehrlich (1974) that named the drivers of ecological forces (i.e., impact, I) as the growth in (i) human population (P), (ii) affluence (A), and (iii) technology advancement (T), i.e., the IPAT, further modifications as illustrated in the literature have yielded the incorporation of other indicators in the model (York et al., 2003; Dietz et al., 2007; Stern, 2004). For instance, Lankao et al. (2008) contend that the ecological consequences of financial upswings are greater in the initial stages of development and opulence (this is measured by capital flow). As countries economically advance through structural reform and modern application of environmental-related innovations, ecological deterioration can be substantially diminished (Ramanathan, 1988; Jung et al. 2000; Gibbs, 2000; Stern, 2004; Bertinelli & Strobll, 2005; Doğan et al., 2022; Balsalobre-Lorente et al., 2023a, 2023b). Theoretically, the diversity of progress must be linked to diverse capacities for dealing with GHG emissions such that a developing country may successfully follow a growth path with limited environmental consequence(s) rather than mere convergence to mature economies (Roberts & Grimes 1997).

Empirical literature

This part is reserved for the discussion of studies that examined the relationship between domestic material consumption aspects (biomass, fossil fuel, metal ores and non-metal ores) and greenhouse gas emission.

Drivers of GHG emission: aggregate DMC and energy components

In a recent study by Alola et al. (2021), the drivers of GHG from the perspective of aggregate domestic material consumption, renewable energy utilization, and income were examined for the case of the 28 European Union (EU) member states. The study performed a series of relevant econometric approaches and found that the aggregated domestic consumption in the EU-28 bloc is detrimental to environmental sustainability in the short and long term. Other indicators such as the renewable energy utilization plays a significant role in mitigating greenhouse gas in both periods while income only offers a desirable environmental effect in the long term. Similarly, Seppälä et al. (2011) employed the aggregated value of material consumption but for the case of Finland to compare the GHG emission arising from imports to and exports from Finland. In this case, environmentally extended input–output (EE-IO) analysis of 150 industries and 918 products in period 2002 and 2005 was performed. Although the result shows no difference between resources utilization from imported and domestic materials, about 70–80% of domestic emissions is traced to life-cycle greenhouse gas emissions by imports. In the same study, result further implies that the service sector share of GHG emission is 44% of total GHG emissions from domestic products utilization.

According to a recent study, Alola and Adebayo (2023) found that biomass, fossil fuel, and metallic ore domestic material utilizations cause GHG emissions of varying impacts across the main active sectors of the economy, i.e., waste management, industrial, and agriculture. The study implemented relevant and recently developed Fourier function approaches for the case of Iceland over the period 1990 to 2019. Mainly, the result of the investigation notes that domestic utilization of metallic ores spurs aggregate economy level GHG emission while the long-run impact of biomass and fossil fuel domestic consumptions are environmentally desirable. On the sector level impact of domestic material utilization, biomass mitigates waste management and agricultural GHG emissions in the long run. Additionally, domestic consumption of metallic ores increases the volume of industrial section GHG emission by an elasticity of 0.24. Although domestic material consumption in the form of fossil fuel has no statistically significant impact on waste management and agricultural GHG emissions, the resources drive industrial GHG emission desirably. Specifically, the finding suggests that fossil fuel materials mitigate industrial GHG emission especially in the long run.

Kefeng et al. (2021) studied the potential of GHG emission remediation of biomass-produced chemicals. Specifically, the study employed a quantitative process to estimate the mitigation capacity of 25 sizable and prospective platform biochemicals. It is worth noting that biomass-based production could dramatically reduce GHG emissions, having 24 of the 25 biochemicals emitting less GHG than their non-renewable energy equivalents. Conservative biochemical factors can as well lower the GHG emissions by 88%, while optimistic predictions can reduce emissions by up to 94%. Meanwhile, Kajaste (2014) explored a content analysis of chemicals from biomass via GHG emissions management in biorefinery production chains. There were uncertainties observed in calculating GHG emissions from logistics and agricultural practices such as feedstock cultivation and harvesting. Moreover, emission of GHG from biorefinery production chains is clearly identified and research on the use of feedstock is primarily through Lignocellulosic, organic waste and algae. Similarly, but for non-renewable energy sources, Karmaker et al. (2020) evaluated the parameters of greenhouse gas emissions via fossil fuel production in Bangladesh. Applying the hybrid optimization of multiple energy resources model (HOMER) model, the level of greenhouse gas emissions from fossil energy facilities was evaluated. This discovery demonstrates that coal power plants emit more CO_2 per kilowatt hour (kWh) (i.e., 0.90 kg) than diesel power plants (0.76 kg) and natural gas power plants (0.566 kg). Because of the high rate of emissions from fossil fuels, other approaches, including a technological approach, were proposed.

Drivers of GHG emission: (non) metal ores

Wei et al. (2020a) researched the relationship between nickel product energy utilization and greenhouse gas emissions for a specific case by employing a model that is built on four main aspects, i.e., mining, pre-processing, smelting, and post-processing. The result shows that manufacturing nickel metal required 174 GJ/t alloy energy and resulted in 14 tCO_2-eq/t alloy, greenhouse gas emissions. Other forms of nickel production such as nickel oxide, ferronickel, and nickel pig iron also produce varying degree of GHG emissions. Carbon emissions were lowered by comparing ore type to electricity source and recognizing nickel production's potential as a more sustainable option. Similarly, especially for other metallic ores, Wei et al. (2020b) examined the energy consumption and GHG emission of four ferromolybdenum production instances vis-à-vis the iron and steel industry. The model employed inventory variables from a system-based model on material

Table 1 Data source, measurement, and variables

Symbol	Variables	Measurement	Source
DMCB	Domestic material consumption biomass	Tonnes	Global Material Flows Database
DMCF	Domestic material consumption fossil fuel	Tonnes	Global Material Flows Database
DMCMO	Domestic material consumption metal ores	Tonnes	Global Material Flows Database
DMCNMO	Domestic material consumption of nonmetal ores	Tonnes	Global Material Flows Database
GHG	Greenhouse gases	Thousand tonnes	WDI
LULGHG	Land use, land use change, and forestry GHG	Thousand tonnes	Eurostat
IGHG	Industrial GHG	Thousand tonnes	Eurostat
AGHG	Agriculture GHG	Thousand tonnes	Eurostat
WGHG	Waste management GHG	Thousand tonnes	Eurostat
EGHG	Energy GHG	Thousand tonnes	Eurostat
GDP	Economic growth	GDP (constant 2015 USD).	Global Material Flows Database
POP	Population	Urban population	World Bank Database

and momentum conservations. According to the data, producing one tonne of FeMo will take more than 29.1 GJ of energy, while GHG emissions correspond to more than 3.16 tCO2 in production of one tonne of energy. Among the four scenarios evaluated, it was revealed that FeMo generated as a byproduct of copper mining seems to have the least environmental impact in terms of energy utilization and GHG emissions.

Additionally, Haque and Norgate (2013) calculated the greenhouse gas (GHG) footprint of several ferroalloy (manganese, chromium, silicon, and molybdenum) production processes in Australia, i.e., the case of Tasmanian electricity greenhouse gas emission. This was accomplished using the life cycle evaluation approach. Ferroalloy manufacture has a GHG footprint of 1.8 t manganese, 2.8 t silicon, and 3.4 t molybdenum alloy. According to the study, the large difference in GHG emissions across the various ferroalloys is mostly due to their differing amounts of power and coal use. As a result, it was determined that GHG emissions from ferroalloy manufacture might be reduced by replacing biomass-based renewable for fossil fuel-based coal. Importantly, the life cycle assessment result reveals that various ferroalloy production processes which account for not less than 60% of GHG emission are linked to coke and coal utilization. In a similar study by Norgate and Jahanshahi (2006), the study evaluates the impact of metal resources grading on energy consumption and GHG emissions. Copper and nickel were employed as metallic ores in the study to investigate the impact of falling ore resources on energy inputs and its correlation to greenhouse gas emissions in metallurgical processes. Due to the higher energy consumed in the mining and mineral handling stages, lowering ore grades had a substantial effect for levels less than 1%, according to the data. The study concluded that smelting these ores directly rather than grinding them is the best option.

Given the review of the related studies above, there is a clear gap in the literature especially with the lack of study that has looked at the emission-related effects of the components of DMC. More so, the current study provides novelty by looking at the environmental-related effects of the components of DMC especially across main sectors.

Data and methods

We evaluate the effect of domestic material consumption on greenhouse gas (GHG)-waste, liquid, agriculture, energy, and industrial. The study also considers economic growth and population in the model. The study utilized data that covers a 31-year period, i.e., between 1990 and 2020. The study focuses on Nordic countries (Sweden, Norway, Iceland, Finland, and Denmark). The measurement, symbol, and source of data are presented in Table 1. In this study, six distinct models were used (mainly of environmental impact function), which are illustrated as follows:

$$\mathrm{GHG}_{it} = f\left(\mathrm{DMCB}_{it}, \mathrm{DMCF}_{it}, \mathrm{DMCMO}_{it}, \mathrm{DMCNMO}_{it}, \mathrm{GDP}_{it}, \mathrm{POP}_{it}\right) \quad (1)$$

$$\mathrm{IGHG}_{it} = f\left(\mathrm{DMCB}_{it}, \mathrm{DMCF}_{it}, \mathrm{DMCMO}_{it}, \mathrm{DMCNMO}_{it}, \mathrm{GDP}_{it}, \mathrm{POP}_{it}\right) \quad (2)$$

$$\mathrm{EGHG}_{it} = f\left(\mathrm{DMCB}_{it}, \mathrm{DMCF}_{it}, \mathrm{DMCMO}_{it}, \mathrm{DMCNMO}_{it}, \mathrm{GDP}_{it}, \mathrm{POP}_{it}\right) \quad (3)$$

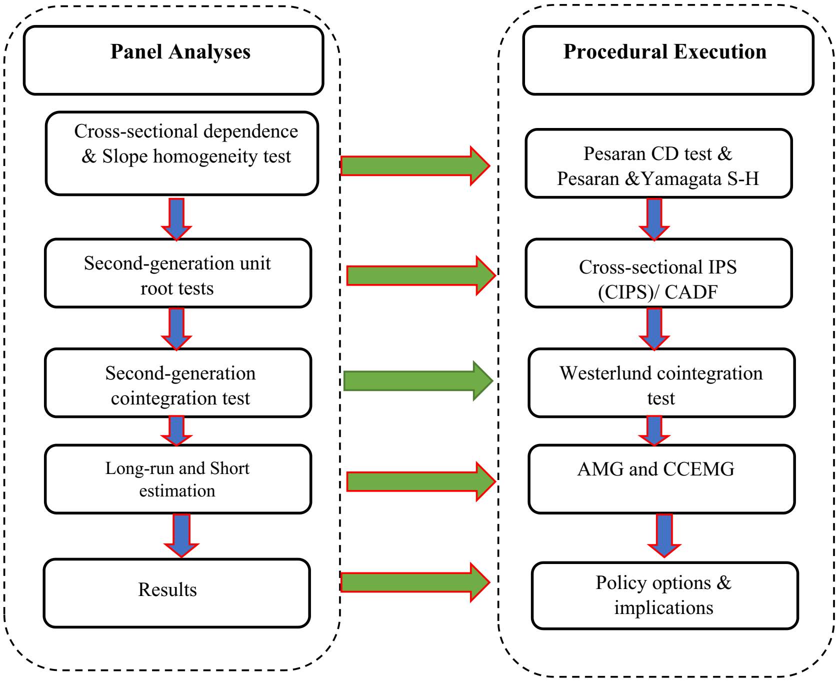
$$LUGHG_{it} = f\left(\mathrm{DMCB}_{it}, \mathrm{DMCF}_{it}, \mathrm{DMCMO}_{it}, \mathrm{DMCNMO}_{it}, \mathrm{GDP}_{it}, \mathrm{POP}_{it}\right) \quad (4)$$

$$AGHG_{it} = f\left(\mathrm{DMCB}_{it}, \mathrm{DMCF}_{it}, \mathrm{DMCMO}_{it}, \mathrm{DMCNMO}_{it}, \mathrm{GDP}_{it}, \mathrm{POP}_{it}\right) \quad (5)$$

$$\mathrm{WGHG}_{it} = f\left(\mathrm{DMCB}_{it}, \mathrm{DMCF}_{it}, \mathrm{DMCMO}_{it}, \mathrm{DMCNMO}_{it}, \mathrm{GDP}_{it}, \mathrm{POP}_{it}\right) \quad (6)$$

where GHG, IGHG, LULGHG, AGHG, WGHG, and EGHG denote greenhouse gases, industrial GHG, land use,

Fig. 1 Flow of analysis



LULCF GHG, agriculture GHG, waste management GHG, and energy GHG. DMCB, DMCF, DMCMO, and DMCNMO signify domestic material consumption of biomass, domestic material consumption of fossil fuel, domestic material consumption of metal ores, and domestic material consumption of nonmetal ores. Furthermore, economic growth and urban population are illustrated by GDP and POP.

Methodology

The approach of this paper is based on Second-Generation methods with the empirical direction illustrated in Fig. 1. This methodology of the investigation was selected for a specific motive. The Nordic nations' shared economic framework means that their structural linkages will show up in the economic spillovers, which may appear as a cross-sectional dependence (CD). This technique is compatible with the study's policy-level input and is logically justified by the paradigm of the empirical approach. The methodological framework is as follows: First, more recently developed unit root tests are used to investigate the variables' stationarity feature. Before examining the long-run relationship between the dependent and independent variables, we employed the 2nd generation cointegration approach after confirming the parameter's stationarity characteristic.

The need to verify the long-term interrelationship between the parameters arises from the cointegration of the variables. We unearthed the long-term interrelationship with two distinct estimators to estimate the coefficients of independent variables. For instance, to provide a quantified effect, Eberhardt and Teal (2010) improved the augmented mean group (AMG) estimator. Pesaran (2006) initially designed this estimator to replace the common correlated effect mean group (CCEMG) estimator. It was designed for a reasonable number of periods and cross-sections. AMG also has the benefit of including time-invariant fixed effects in the framework. A typical dynamic effect parameter is also included. There are two steps to using this (AMG) estimator:

$$\text{Step i}: \Delta y_{it} = \alpha_i + \beta_i \Delta x_{it} + \gamma_i \zeta_t + \sum\nolimits_{t=2}^{T} d_i \Delta D_t + \varepsilon_{it} \tag{7}$$

$$\text{Step ii}: \hat{\beta}_{AMG} = N^{-1} \sum\nolimits_{i=1}^{N} \hat{\beta}_i \tag{8}$$

where the difference operator is denoted by Δ; the observables are depicted by y_{it} and Δx_{it}; the country-specific estimation coefficient is depicted by β; ζ_t stands for an undetected common component with a heterogeneous factor; conventional dynamic process and coefficient time dummies are shown by d_i. The mean group estimator is depicted by $\hat{\beta}_{AMG}$. The intercept and error terms are shown by α_i and ε_{it}, respectively.

Furthermore, Eberhardt and Bond (2009) provided evidence that both CCEMG and AMG successfully handled cross-sectional dependence and root mean square errors found in panel data with nonstationary variables in Monte Carlo simulations. AMG estimator has been employed in some prior studies, such as Kong et al. (2020) and Ojekemi et al. (2022), but no studies have tested the long-run link in the current setting using AMG estimator. Again, after obtaining the AMG estimators, a robustness estimation is performed by using the CCEMG approach. The CCEMG

Table 2 Slope heterogeneity test outcomes

	GHG model	IGHG model	AGHG model	LUGHG model	WGHG model	EGHG model
$\hat{\Delta}$	5.621*	6.291*	8.593*	10.043*	6.723*	7.639*
$\hat{\hat{\Delta}}_{\text{adjusted}}$	6.563*	7.347*	9.860*	11.985*	7.012*	8.749*

* depicts 1% level of significance

technique, which was initially put forward by Pesaran (2006) and further streamlined by Kapetanios et al. (2011) is helpful for the cross-sectional dependence scenario. This estimator yields excellent outcomes if the data contain multifactor error terms and panel heterogeneity. Thus, CCEMG is depicted as follows:

$$m_{it} = \varnothing_{1i} + \tau_1 z_{it} + \vartheta_i p_t + \beta_i \overline{m}_{it} + \gamma_i \overline{z}_{it} + \varepsilon_{it} \tag{9}$$

where the observable parameters are depicted by m_{it} and z_{it}, p_t has heterogeneous coefficients and is an unobservable common factor, and country-specific estimate coefficient is depicted by τ_1. The intercept term and error-term are depicted by $\varnothing_{1i}$ and ε_{it}, respectively.

Findings and discussions

We examine each model's slope heterogeneity. This test assists in determining whether first- or second-generation econometric approaches should be employed in subsequent analyses in conjunction with the CD test. Table 2 shows the findings of the slope heterogeneity test. Regarding the six regression equations (GHG Model, IGHG Model, AGHG Model, LUGHG Model, WGHG Model, and EGHG Model), the two tests statistic of $\hat{\Delta}$ and $\hat{\hat{\Delta}}_{\text{adjusted}}$ dismiss the Ho hypothesis of "slope homogeneity" at a significance level of 1% in each model proving that each model has slope heterogeneity. It means that GHG, IGHG, AGHG, LUGHG, WGHG, and EGHG regression analysis may yield false conclusions and deceptive findings if slope homogeneity constraints are assumed. The CD test is a crucial evaluation of dynamic panel data. If the portions were dependent, failing to account for their heterogeneity would lead to inaccurate modeling and reduced estimation effectiveness. Table 2 presents the CD results of the CD test. According to the results of the CD test, the null hypothesis is rejected at a 1% significance level.

The present study employed the cross-sectionally augmented Im, Pesaran and Shin (CIPS) unit root test created by Pesaran (2006) after verifying the CD in the panel data since this test produces reliable findings in the presence of CD (Adebayo et al. 2022). Table 3 shows the results of the CIPS and Covariate Augmented Dickey-Fuller (CADF) unit root tests. The analysis was initially used on a level before being applied to the first variable difference. The CIPS and CADF unit root tests reveal that the relevant variables have nonstationary and stationary characteristics. At the significance level of 1%, all the variables are stationary at order I (1). Based on this information, we proceed to evaluate the cointegration interconnection between variables in the six models.

The findings of the cointegration test, i.e., the long-term cointegration connection between variables, are shown in Table 4. The test's null hypothesis of "no cointegration" is dismissed in the six models. Therefore, we affirmed the long-run connection between the variables in the six models. This suggests that the variables have a long-term interrelationship.

Coefficient estimations

The CCEMG and AMG long-run estimators which considers CD and heterogeneity effect were employed to obtain the coefficients of the long-term interrelationships between the variables (see Tables 5 and 6). The presented result in Table 6, which largely aligns with the main estimations displayed in Table 5, serves as robustness evidence.

In Table 5, regarding the effect of domestic material consumption biomass (DMCB) on greenhouse gases (GHG), industrial GHG (LGHG), agriculture GHG (AGHG), waste management GHG (WGHG), energy GHG (EHGH), land use, land use change, and forestry GHG (LUGHG), we obtained interesting results. The effect of domestic material consumption biomass on greenhouse gases (GHG), waste management GHG, energy GHG, land use, land use change, and forestry GHG is positive and significant. This increase indicates that biomass domestic consumption contributes to the intensification of greenhouse gases (GHG), waste management GHG, energy GHG, land use, land use change, and forestry GHG. These results comply with the studies of Bilgili (2012), Zafar et al. (2022), and Adewuyi and Awodumi (2017), who reported a positive association between biomass consumption and ecological deterioration. On the other hand, the effect of domestic material consumption biomass on agriculture GHG is negative, which implies that domestic material consumption biomass aid in curbing agriculture GHG. Our findings show that biomass energy functions as a renewable energy alternative, which helps the Nordic economies reduce emissions by mitigating their agriculture GHG. In the Nordic countries, this energy source is widely available, and its combustion is environmentally friendly.

Table 3 CD and CIPS and CADF test outcomes

	CD outcomes		CIPS outcomes		CADF outcomes	
	Pesaran CD	*P* value	*I(0)*	*I(I)*	*I(0)*	*I(I)*
DMCB	4.3997	0.000	−1.910	−5.113*	−2.018	−4.274*
DMCF	3.7895	0.000	−2.161	−5.574*	−2.203	−4.741*
DMCMO	4.8142	0.000	−2.362	−5.391*	−2.338	−5.634*
DMCNMO	3.9913	0.000	−2.118	−5.170*	−2.180	−5.071*
GDP	16.901	0.000	−1.879	−4.089*	−2.326	−4.408*
POP	16.267	0.000	−1.226	−2.257***	−1.448	−3.126*
GHG	3.0737	0.282	−2.186	−5.498 *	−2.183	−4.623*
AGHG	8.3917	0.000	−2.053	−5.373*	−2.048	−4.390*
IGHG	1.3493	0.177	−2.043	−4.656*	−2.504	−4.909*
LUGHG	1.9070	0.056	−1.211	−2.447***	−1.204	−3.828*
EGHG	6.5301	0.000	−1.623	−5.039*	−1.801	−4.301*
WGHG	9.8808	0.000	−0.514	3.782*	−1.324	−4.484*

***, **, and * depict 10%, 5%, and 1% significance levels

Table 4 Westerlund cointegration outcomes

	GHG model	IGHG model	AGHG model	LUGHG model	WGHG model	EGHG model
Gt	−7.574*	−8.362**	−8.107*	−7.281*	−6.911*	−7.453*
Ga	−13.902*	−14.927*	−14.008*	−13.532*	−12.025*	−13.872*
Pt	16.729*	−17.735**	−16.907*	−15.893*	−13.832*	−15.640*
Pa	15.903*	−15.027**	−15.735*	−14.385*	−11.592*	14.063*

** and * depict 5% and 1% significance level

Table 5 Augmented mean group outcomes

	GHG model	IGHG model	AGHG model	LUGHG model	WGHG model	EGHG model
DMCB	0.1676 (1.807)***	−0.0570 (0.571)	−0.0169 (1.981)***	0.3271 (2.182)**	0.0974 (1.860)***	0.1475 (3.118)*
DMCF	−0.0360 (−0.189)	0.0961 (1.425)	0.0030 (0.127)	0.0910 (1.790)***	−0.1105 (−1.525)	0.0785 (1.957)***
DMCMO	0.0388 (0.558)	0.0713 (1.782)***	0.0316 (1.780)***	0.0129 (1.883)	0.0392 (2.314)**	0.0265 (2.326)**
DMCNMO	−0.0024 (−1.052)	−0.0555 (2.196)**	−0.0088 (−1.926)***	0.0195 (1.408)	−0.0524 (−1.957)***	0.0397 (1.310)
GDP	0.9752 (2.986)*	0.8945 (2.271)**	0.1354 (1.714)***	0.6722 (2.107)**	0.5929 (2.056)**	0.5350 (5.130)*
POP	−4.6443 (−0.221)	−12.225 (2.139)**	0.9504 (0.970)	0.8751 (2.227)**	1.6431 (0.374)	4.5719 (3.051)*
RMSE	0.0548	0.0525	0.0080	0.0521	0.0166	0.0222

***, **, and * depict 10%, 5%, and 1% significance levels. Value in the ( ) denotes the *T*-statistics

Table 6 Common correlated effects mean group outcomes

	GHG model	IGHG model	AGHG model	LUGHG model	WGHG model	EGHG model
DMCB	0.4934 (2.141)**	−0.0330 (−0.170)	−0.0339 (1.807)***	0.0187 (12.83)*	0.0974 (1.860)***	0.1990 (2.581)*
DMCF	−0.0073 (−1.114)	0.20084 (1.305)	.0093913 (0.458)	0.0082 (4.936)*	−0.1105 (−1.525)	0.0089 (1.871)***
DMCMO	0.0710 (0.986)	0.2008 (1.815)***	.01970 (2.419)**	−0.0033 (2.653)*	0.0392 (2.314)**	0.0404 (2.024)**
DMCNMO	−0.0445 (−0.568)	−0.1036 (2.014)***	−.041282 (3.520)*	0.0402 (2.391)**	−0.0524 (−1.957)***	0.0889 (1.841)***
GDP	0.1533 (2.680)**	0.0812 (2.874)*	.149368 (2.631)**	0.2572 (1.986)***	0.5929 (2.056)**	0.6339 (3.537)*
POP	−4.6398 (−1.318)	−8.8660 (3.072)*	1.78177 (0.819)	2.3406 (1.832)**	1.6431 (0.374)	4.7233 (1.784)***
RMSE	0.0108	0.0369	0.0080	0.0019	0.0166	0.0174

***, **, and * depict 10%, 5%, and 1% significance level. Value in the ( ) denotes the *T*-statistics

This outcome complies with the research of Awosusi et al. (2022) on the nexus between biomass and ecological footprint, which reported that a decrease in ecological footprint is attributed to the upsurge in biomass energy consumption.

Moreover, the effect of domestic material consumption of fossil fuel (DMCF) on LUGHG, EGHG, and WGHG is positive and significant. The results indicate that fossil fuel consumption in Nordic countries also increases LUGHG, EGHG, and WGHG, respectively. This confirms the conclusions of Adebayo (2022), Akadiri et al. (2022), and Onifade et al. (2022) that the usage of fossil fuels is significantly causing the surge in LUGHG, EGHG, and WGHG, thus contributing to environmental deterioration in Nordic countries. This empirical evidence is not surprising, given that fossil fuels are utilized to boost economic growth and satisfy expanding energy demands. Evidently, some of the examined countries still largely relies on fossil fuel sources for heating and for other economic activities, which results in LUGHG, EGHG, and WGHG, and other harmful substances.

Additionally, the result found that domestic material consumption of metal ores (DMCMO) impacts GHG, IGHG, AGHG, WGHG, and EGHG significant and positive, suggesting that DMCMO contributes to the intensification of ecological deterioration in the Nordic nations. It shows how the environment is harmed by increased DMCMO in the Nordic countries. Furthermore, we utilized ores and metal ore following the study of Gyamfi, Adebayo et al. (2022) and Gyamfi, Agozie et al. (2022). By claiming that DMCMO, which is also a natural resource, is purportedly used in significant quantities for agriculture, deforestation, and mining, all of which have negative environmental effects. Our result is consistent with the studies of Afshan and Yaqoob (2022), Awosusi et al. (2022), Caglar et al. (2022), and Hassan et al. (2019). Most of the iron ore is used to make iron, which is then used to make steel. The manufacturing of steel uses 98% of the iron ore that is currently produced. This comprises automobiles, steel beams utilized in building, construction, and everything else that requires iron or steel. Iron ore mining consumes a lot of energy and results in environmental pollution from diesel generators, trucks, and other machinery that emits carbon dioxide, sulfur dioxide nitrous oxide, and carbon monoxide. The extraction of iron ore also contaminates acid and heavy metals that leak from the mines. Additionally, our empirical findings are confirmed by Muhammad and Khan (2021) and Yang et al. (2022). The increasing industrialization and modernization process, which has increased natural resource exploitation in 88-BRI nations, may be the reason for the positive interrelationship between natural resources and environmental deterioration. Our findings, nevertheless, conflict with those of Balsalobre-Lorente et al. (2018). These findings support the concept that emissions from natural resources occur in B&R countries. The conclusion implies that increased demand for natural resources to achieve rapid economic growth may pose long-term harm to the quality of the environment. On the other side, domestic material consumption-non-metal ores (DMCNMO) impact IGHG, AGHG, and WGHG negatively, suggesting that consumption of DMCNMO enhances the quality of the ecosystem.

Furthermore, we found a positive association between economic expansions and ecological deterioration in all six models (GHG, IGH, AGHG, LUGHG, WGHG, and EGHG). The empirical results showed that the economic growth coefficient is significant and positive, indicating that an increase in economic progress causes an upsurge in ecological deterioration in the Nordic countries. The increase in income has increased resource use across all industries. This result is in line with those of Jahanger et al. (2022), Alola et al. (2019), and Ahmad et al. (2021). It may be inferred that Nordic countries have benefitted from their economies' core industries, notably transportation, agriculture, and manufacturing. An alternate explanation for the rise in emissions is that economic expansion promotes economic activities by raising investments, consumption, energy usage, and purchases (Akadiri et al., 2022).

Two results surfaced regarding the association between population (POP) and environmental deterioration. Firstly, the GHG and IGHG model results reveal that POP negatively affects the environment's deterioration. This result partially aligns with the result reported by Kongkuah et al. (2022), who reported that an upsurge in POP causes a decrease in ecological deterioration. Secondly, the POP coefficient has shown that an increase in POP will greatly increase both LUGHG and EGHG, and this largely aligns with a priori expectation. This suggests that industrial activities in the Nordic countries are probably becoming less human capital intensive in comparison with the energy, and land use, land use change, and forestry sectors. Our results are comparable to those of Faisal et al. (2021) and Ngoc et al. (2021). Moreover, Zhang et al. (2021) documented a similar result in the case of Malaysia. Specifically, Zhang et al. (2021) opines that the present political climate motivates rural residents in Malaysia to move to cities in quest of greater job opportunities and better public services, thus complicating the environmental situation of the urban areas. POP greatly impacts energy utilization in the building, residential, and transportation sectors. In addition, POP contributes to environmental degradation through increased waste output and demand for resources like infrastructure, water, food, and other things (Gyamfi, Adebayo, et al., 2022; Yang et al., 2022).

Conclusion and policy recommendation

The contribution of this study highlights the approach to the ambition of the Nordic countries from different fronts: green and circular economy, sustainable production and consumption, and carbon neutrality targets, among other related

SDGs. While the role of biomass, fossil fuel, metallic ores, and non-metallic ores domestic consumptions especially in (dis)aggregated GHG emission is examined in the period 1990–2020, interesting results ensued. By deploying the competency of long-run coefficient-examining econometric tools, i.e., AMG and CCEMG which account for CD and heterogeneity in the panel, unanimous results are presented by both estimators.

On the GHG emission components, biomass domestic material utilization spurs emissions from LULCF, waste management, and energy while reducing agricultural GHG emission at statistically significant levels. Additionally, domestic consumption of fossil fuel materials only spurs LULCF, waste management, and energy GHG emissions. The results of the domestic consumption of metallic and non-metallic ores are quite dissimilar in the sense that utilization of metallic ores spurs GHG emissions in the industrial, agricultural, LULCF, waste management, and energy sectoral activities. On the other hand, domestic consumption of non-metallic ores statistically mitigates GHG emissions arising from the activities in the industrial, agricultural, and waste management processes.

Importantly, the results revealed that only domestic material consumption of biomass shows a statistically significant impact on the aggregated GHG emission thereby spurred GHG emissions in the panel. Additionally, on the aggregated GHG emission, economic growth, i.e., GDP also exerts a statistically significant positive impact while also exerting significant positive impacts on industrial, agricultural, LULCF, waste management, and energy GHG emissions. Moreover, population caused a statistically significant and negative impact on GHG emissions in the said period and a negative impact on industrial GHG emission but caused a statistically significant and positive impact on LULCF and energy GHG emissions.

Policy recommendation

The highlighted results obviously offer relevant policy directives especially from the indications of material consumption components and emission-characterized activities. For instance, biomass material consumption seems to be a good ploy toward mitigating GHG emission only in the agricultural sector, as such there should be more expansive farmers' access to biomass material possibly through policy adjustment targeted at the raw material sources. Except in the waste management activities where fossil fuel materials mitigate GHG emission, otherwise adoption of energy transition policy should be well-encouraged across the sectoral activities. Importantly, stakeholders driving the greening and circular economy in the Nordic countries need to focus on ensuring an effective decarbonization approach in the examined sectors. For instance, should the export activities in metallic ores be associated with the undesirable GHG emission, further approach targeted at re-assessing the export activities' network could yield a desirable environmental and greening economy outcome. In spite of the policy relevance of the findings, there are obvious limitations associated with the investigation that could be improved upon in a future implementation. For instance, a future study could consider the GHG emission effects of more granular sub-components of the various aspects of DMC. Additionally, besides the role of population, the role of other key socioeconomic and demographic indicators could be a great interest in a future investigation.

Author contributions Andrew Adewale Alola: Conceptualization, Data curation, Discussion of results, Writing introduction and literature review, Editing, Corresponding. Tomiwa Sunday Adebayo: Methodology, Analysis, and Discussion of results. Ishaaqa Olagunju: Writing literature review.

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