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The making-or-breaking of material and resource efficiency in the Nordics

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A R T I C L E I N F O

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A B S T R A C T

The relevance of efficient direct material input through both export market and domestic material sources offers useful material and resource productivity guidelines from both economic and environmental sustainability dimensions. In the current context, the drivers of material and resource efficiency in the Nordic region are examined by utilizing requisite empirical approaches over the period 1995–2020. The investigation revealed that economic activities which are characterized by Gross domestic product (GDP) alongside the growth of urban population and utilization of oil energy are all detrimental to the region's resource efficiency. It implies that material utilization efficiency cannot be optimized with the current trend of the region's GDP, urban population growth and the use of dirty energy. Contrarily, the findings, further revealed that alternative energy utilization vis-à-vis renewables are key indicators to spur material and resource efficiency in the region, thus throwing more support for the region's unavoidable energy transition goal. These highlighted results alongside the Granger causality inference offer sustainable development measures that are specifically motivated through the improvement of efficient and optimization of output.

1. Introduction

The industrial revolution, partly a characterization of transition to a "coventional energy system" arising from socio-metabolism between regimes (Haberl et al., 2011; Fischer-Kowalski et al., 2014), has resulted in sharp increase in the consumption of energy and resources amidst increase in population. With increase in the world population to over eight billion, utilization of natural resources are fast becoming very competitive given it critical factor to survival and sustainable development (Bekun et al., 2019; Lampert, 2019; Onifade et al., 2023). According to economic theory, providing services combined with manufacturing things for human consumption includes using raw materials. Given the increased reliance on international trade for raw material acquisition, a resource shortage for some essential resources include oil & helium, and the rising costs of primary materials, policy attention to natural resource security is expanding globally (European Commision, 2011). Therefore, natural resources are of interest because of the raw materials they provide, which have a high critical value globally and are particularly valuable in the European region due to the region's economic importance and supply risk (Kassouri et al., 2021; Alola and Adebayo, 2022).

Material productivity has drawn much attention as a general indicator of environmental sustainability. More materials are needed for manufacturing and consumption as the global economy expands. The increase in natural resource use has become the main barrier to sustainable development. Consequences of this growth include the exhaustion of natural resources, waste emissions, loss of biodiversity, environmental pollution, desertification and climate change (Behrens et al., 2007; United Nations Environment Programme, 2016). Enhancing

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Abbreviation

ARDL:	Auto-regressive distributed lag
CADF	Covariate-augmented Dickey Fuller
CSD	Cross sectional dependence
DMC	Domestic material consumption
DOLMG	Dynamic ordinary least squares mean group
ECI	Economic complexity index
ET	Environmental-related technologies
EPR	Extended producer responsibility
LM	Lagrange multipliers
MFA	Material flow analysis
OECD	Organisation for Economic Co-operation and Development
PDOLS	Panel dynamic ordinary least squares
RE	Random effect
RMP	Raw material productivity
UP	Urban population

material productivity can increase economic advantages while using fewer natural resources, which, in some cases, may be a suitable solution to address potential rising demand and restricted natural resource availability. Researchers have opined that efficient use of material resources can help mitigate greenhouse gas emissions (Hertwich et al., 2019; Pauliuk et al., 2021) while, others argue that material resources have negative impact on the environment (Miatto et al., 2021). In order to ensure prosperity and competitiveness while minimizing environmental damage, the European Union (EU) has created numerous programmes and projects with lofty goals for improving resource efficiency and environmental productivity (European Commision, 2011). Specifically, the Extended Producer Responsibility (EPR) and Green Public Procurement (GPP) are two examples of such initiatives that aim to produce effective and efficient results from an environmental standpoint.

Moreover, the Nordic countries which are among the wealthiest countries in Europe are also at the forefront of sustainable development (Willy, 2015). According to NordForsk (2022), it is interesting to note that these Nordic economies are leading the way in expanding the green economy. The "green economy," which includes a variety of governmental initiatives to keep economic operations within ecological bounds, has gained relevance in political and scholarly discourse. Specifically, the Nordic region relies on its Vision 2030 which is an action plan that is geared toward executing the region's sustainable development between 2021 and 2024 (Nordic Co-operation, 2022). Adopting green technologies is one of the steps that must be taken to meet the challenging environmental and economic objectives while driving sustainable development and productivity.

In pursuing the objective of the current study i.e., examining the drivers of material productivity, the roles of energy-related and socioeconomic variables have been considered in the study given it relevance to climate change debate. Specifically, the variables of interest include: urban population, which puts pressure on resource use, especially energy intensity (Eyyüboğlu et al., 2022); gross domestic product; environmental-related technology, a variable that has been established to have a relationship with productivity (Shah et al., 2022); economic complexity (Lasisi et al., 2022), oil energy source (Ren et al., 2018), and natural gas (Chrulski and Łaciak, 2021). Consequently, the main question that is answered in the study illustrates how the impact of disaggregate energy forms, economic complexity, and other socioeconomic factors on raw material productivity are quantified among the Nordic states. Given that the role of economic complexity and energy sources in material productivity has rarely been explored in the literature, this study supposedly offers a unique perspective. Therefore, the outcome of the study posits crucial inference for better resources efficiency across their life cycles and economies, not just considering the skyrocketing prices of raw materials.

The rest of the paper is structured as follows, section 2 gives an overview of theories related to material productivity and gives a brief review of related literature. Then, section 3 explains the data, econometric method and the results, while section 4 concludes the study and offers some policy insights.

2. Literature review

Any critique of industrialization and economic modernization must always include the connection between economic expansion and environmental deterioration (Meadows et al., 1972). In the 1970s, the earliest studies on material consumption and efficiency were carried out, with the main focus being on the intensity of the use of materials. Globally, both developed and developing countries are looking for fresh approaches to minimize the depletion of their natural resources.

2.1. Theoretical background

The material and energy that enters a society or economy as inputs and exit again as outputs are revealed by the Material Flow Analysis, a method for measuring the socioeconomic metabolism of societies (Eurostat, 2001). Monitoring and analyzing the physical fluxes of materials into, though, and out of a particular system is known as material flow analysis. The analysis's primary area of interest is the connections between material movements and environmental changes.

Material Flow Analysis (MFA) methodological foundations and accounting methodologies have been the topic of previous studies (Schütz and Steurer, 2001; Organisation for Economic Co-operation and Development, 2008; Fischer-Kowalski et al., 2011). According to Ozturk and Acaravci (2016) and Ullah et al. (2020), the Heckscher-Ohlin theory also shows that a nation should design its manufacturing and export product basket according to the manufacturing sector's factor intensity. The fundamental tool for our methodology is the panel dynamic least squares estimator, which explains the factors affecting material productivity.

2.2. Review of related literature

Several papers, including Giljum et al. (2008); Schandl and West (2010); Steger and Bleischwitz (2011), and West et al. (2014) have focused on material productivity to illustrate raw material use. To further understand the inelastic character of the total material productivity indicator, Steinberger and Krausmann (2011) analyzed the response of income to consumption of several types of materials. Gan et al. (2013) investigated the key factors influencing resource productivity by computing a simulation model for a global sample of 51 nations. Regression analysis was used by Van der Voet et al. (2004) to analyze the effects of socioeconomic factors on material productivity utilizing panel data from the EU. They argued that income level and economic structure significantly explain the variations in material productivity.

Notably, Steger and Bleischwitz (2011) used MFA and regression analysis to determine the key factors that influence resource use and the decoupling of it from GDP to understand the system dynamics of material use better. Drivers were defined as those elements that impact how humans use resources in their daily lives. For the European Union, panel data was collected for 1980–2000 (EU–15) and 1992–2000. (EU-25). It was discovered that energy efficiency, the construction of new homes, and road construction activities were the key drivers of resource utilization. Additionally, Agnolucci et al. (2017) used the case of 32 European countries over 2000–2014 to investigate the causal relationship between GDP and domestic material consumption (DMC). The authors demonstrate that while the effect of GDP growth is negligible for the economies of Eastern Europe and the rest of Europe, increasing the GDP growth rate leads to the rise in growth rate of DMC in Western Europe.

Moreover, Kerner and Wendler (2022) evaluated changes in resource productivity convergence for over 100 independent countries from 1970 to 2012 using an ordered logit model. The role of the key determinants of convergence patterns was also examined, along with comparing these patterns to labour productivity. In the study, club convergence is being demonstrated in resource productivity rather than general convergence, with club convergence closely tracking levels of economic progress. The clubs converged on different productivity levels but the same growth rates. They discovered that club membership is closely related to initial per capita income, population density and human capital. Similarly, for 28 EU nations between 2000 and 2018, Alatas et al. (2021) examined the connection between resource productivity, as determined by GDP per DMC, and energy production. They discovered five resource productivity convergence clubs, each showing only relative convergence. Overall, these studies highlight the need for an in-depth study of factors that affects material productivity.

Other factors such as technology, population, and trade related aspects have also demonstrated significant impact on both material and resource productivity (Wang et al., 2016; Yu et al., 2017). For instance, Wang et al. (2016) implemented the auto-regressive distributed lag (ARDL) approach to establish that role of technological advancement, trade openness among other factors in the dynamic of material productivity in China over the period 1980 to 2010. The result found that improvement in technology which causes a decrease in energy intensity for secondary industry especially in the long run is the main driver that vastly increase material productivity. Meanwhile, the role of trade openness in driving material productivity is not spontaneous in both short and long run. On their part, Yu et al. (2017) established that technology, resource quality, and economic structure are key driving factors of resource productivity also in China and over the same period 1980–2010. The investigation suggests that resource productivity is positively driven by economic structure such as increase in tertiary industry and the utilization of higher grades of resources such as higher metal ore grades. Importanlty, from the technological perspective, the result reveals that increase in expenditure intensity through research and development (R&D) spurs resource productivity.

2.3. Contribution to the literature

However, while there seems to be sparse information on the role of economic complexity (a recently developed indicator) in material/resource productivity, the case of the small open economies such as the Nordic is largely undocumented. Moreover, the current study extends the (one sided) literature on the aspects of economic complexity-environmental sustainability nexus in the context of material productivity. For instance, as one of the most recent documentation, Alola et al. (2023) only addresses the environmental sustainability aspect of economic complexity. In the study, Alola et al. (2023) considered the panel of Denmark, Finland, Norway, and Sweden by investigating the impact of economic complexity on environmental deterioration vis-a-vis greenhouse gas (GHG) emissions over the time 1995 to 2020. By using the Driscoll-Kraay's standard errors for random effect (RE) with individual effects, the findings show that the level of economic complexity in the area is favorable to environmental sustainability.

3. Method

This study investigates the factors affecting resource/material productivity for the Nordic states (Denmark, Finland, Norway, Sweden). The dataset utilized for the panel study covers the period 1995–2020. A summarized information about the sources and unit of measurements of the dataset are documented in Table 1 (see the appendix). In this investigation, key econometric approaches of Dynamic Ordinary Least Squares Mean Group (DOLMG) and Panel Dynamic Ordinary Least Squares (PDOLS) by Pedroni (2001) are implemented as coefficient estimators alongside the Granger causality approach inspired in the study of Emirmahmutoglu and Kose (2011). Consequently, two-model approaches are implemented to appropriately account for potential econometric drawbacks. For instance, in Model 1, the Panel Fisher causality test developed by Emirmahmutoglu and Kose (2011), which is used in heterogeneous panels is employed, and for Model 2, the Panel Granger causality test, which is suitable for usage in homogeneous panels is utilized. This is because preliminary tests suggest that models 1 and 2 are respectively heterogeneous and homogeneous panels. The two models that both understudy the drivers of resource productivity (*rmp*) are established for the purpose of the study as follows.

$$Model1{:}rmp_{it} = \beta_{0i} + \beta_{1i}up_{it} + \beta_{2i}gdp_{it} + \beta_{3i}oil_{it} + \beta_{4i}gas_{it} + \mu_{1it} \quad (1)$$

$$Model2{:}rmp_{it} = \alpha_{0i} + \alpha_{1i}lnet_{it} + \alpha_{2i}eci_{it} + \alpha_{3i}lnrene_{it} + \varepsilon_{1it} \quad (2)$$

For lack of space, and the literature-wide documentation of the mentioned techniques, the step-by-step presentation of these econometric approaches are not outline here. Notwithstanding, the material flow analysis (Eurostat, 2001) provides a framework that outlined relevant indicators to engineer the above models and similar to the environmental model proposed by Holdren and Ehrlich (1974).

3.1. Empirical approaches and results

Fig. 1 illustrates the trend of resource/material productivity for Nordic countries. As can be seen from the figure, the trend of Finland's resource/material productivity is the lowest among Nordic countries over the period. For Denmark, the trend was high in mid-nineties and dropped particularly to its lowest in 1999. However, after the global financial crisis of 2008, the trend begins to rise and subsequently become the highest Nordic country in terms of resource/material productivity. The trends of resource/material productivity in Norway and Sweden have been overlapping, although higher than Denmark before the incidence of global financial crisis.

In Table 2, in addition to the GDP for obvious reason, renewable energy consumption, urban population, and environmental-related technologies have large mean scores. Additionally, the standard deviation of renewable energy consumption, urban population, and environmental-related technologies is large, suggesting that variations in these variables are high. In the same vein, the minimum and maximum values of renewable energy consumption, urban population, and environmental-related technologies are higher than other variables used in this study. Therefore, to avoid heteroscedasticity problem, it is sensible econometrically to take the natural logarithm of these variables.

The correlation matrix analysis is performed for the variables. The results as presented in Table 3 indicate that material productivity is positively correlated with urban population, GDP, Oil, environmental-related technologies, and renewable energy while it is negatively correlated with gas, and economic complexity. Urban population has a positive and significant correlation with all the variables except gas and renewable energy. For GDP, Oil, environmental-related technologies, and renewable energy consumption are positively and significantly correlated with GDP while gas and economic complexity have a negative correlation with GDP. Furthermore, the correlation between Oil and gas, and again, Oil and environmental-related technologies are negative and statistically significant while the correlation between Oil and economic complexity and again, oil and renewable energy consumption are positive and statistically significant. In addition, gas has a negative and significant correlation with environmental-related technologies, economic complexity, and renewable energy while environmental-related technologies are positively correlated with economic complexity and renewable energy consumption even though the correlation is not statistically significant. There is evidence that economic complexity has a negative and insignificant correlation with renewable energy consumption. Generally, from the coefficients of the correlation matrix, the

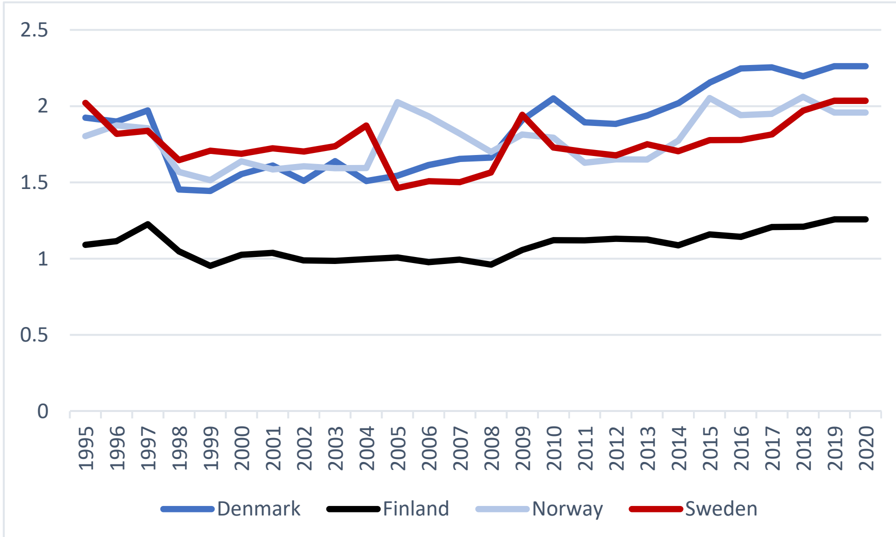

Fig. 1. Resource/material productivity (in USD/KG) for four Nordic Countries.
Source. Global Material Flows Database

Table 2
Descriptive statistics of the variables.

Variable	Obs	Mean	Std. Dev.	Min	Max
rmp	104	1.619401	0.360598	0.9533	2.2621
et	104	11.69298	5.514208	4.05	23.37
gas	104	0.115769	0.054607	0.03	0.2
eci	104	1.413174	0.51497	0.359254	2.291723
oil	104	0.472692	0.129136	0.26	0.83
rene	104	10089.82	4905.411	1298.257	19578.37
gdp	104	3.19E+11	9.20E+10	1.53E+11	5.46E+11
up	104	83.36763	3.507993	73.787	87.994

issue of multicollinearity might not arise in this study.

In addition, the empirical approach follows the tradition in the literature by using the variance inflation criterion (VIF) to detect the presence of a multicollinearity problem. To this extent, Table 4 illustrates the VIF test results. Since both VIF and Mean VIF results for Model 1 and Model 2 are less than 5, it suggests, therefore, that there is no multicollinearity problem in the two models for this study.

From the panel data analysis, it is found that the presence of dependence factors across the examined panel i.e cross sectional dependence (CSD) may render the results imprecise and spurious. Therefore, in this study, prior to estimations of our models, CSD in the study is tested by employing several CSD tests which include the variable CSD tests of Breusch-Pagan cross Lagrange Multipliers (LM) test, Persaran scaled LM test, Bias-corrected scaled LM test, and Pesaran CD test as Breusch and Pagan (1980) and Pesaran and Yamagata (2008; 2015). The results as shown in Table 5(a), reveal that the null hypothesis of no cross-sectional dependence could not hold in all variables. For CSD based on models used, the results in Table (5b) provide also that the null hypothesis of no cross-sectional dependence for Model 1 and Model 2 is rejected. That is, these models have cross-section dependence.

Table 4
VIF test results.

Model 1			Model 2		
Variable	VIF	1/VIF	Variable	VIF	1/VIF
gas	2.68	0.37	eci	1.02	0.98
oil	2.33	0.42	lnert	1.01	0.98
lngdp	1.35	0.74	lnrene	1.00	0.99
up	1.14	0.87			
Mean VIF	1.88		Mean VIF	1.01	

Table 5a
CSD test results.

Variable	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
rmp	0.00*	0.00*	0.00*	0.00*
lnet	0.00*	0.00*	0.00*	0.00*
gas	0.00*	0.00*	0.00*	0.14*
eci	0.00*	0.00*	0.00*	0.00*
oil	0.00*	0.00*	0.00*	0.00*
lnrene	0.00*	0.00*	0.00*	0.00*
lngdp	0.00*	0.00*	0.00*	0.00*
up	0.00*	0.00*	0.00*	0.00*

Note. The values in the table give the probability values. * Indicates that the null hypothesis was rejected at 1%.

Table 3
Correlation analysis results.

	rmp	*up*	*lngdp*	*oil*	*gas*	*lnet*	*eci*	*lnrene*
rmp	1.000							
up	0.136	1.000						
lngdp	0.634*	0.156	1.000					
oil	0.0236	0.091	0.434*	1.000				
gas	−0.127	−0.302*	−0.498*	−0.734*	1.000			
lnet	0.174***	0.658*	0.228**	−0.276*	−0.248**	1.000		
eci	−0.446*	0.456*	−0.183**	0.613*	−0.566*	0.113	1.000	
rene	0.003	−0.278*	0.540*	0.431*	−0.617*	0.031	−0.043	1.000

Note. *, ** and *** indicate that the null hypothesis was rejected at 10%, 5% and 1%, respectively.

Table 5b
CSD test results for Model 1 and Model 2.

Model 1			Model 2		
Test	Statistic	p-value	Test	Statistic	p-value
LM	15.73	0.02**	LM	45.52	0.00*
LM adj*	6.143	0.00*	LM adj*	28.93	0.00*
LM CD*	2.61	0.01**	LM CD*	6.291	0.00*

Note. * and ** indicate that the null hypothesis was rejected at 5% and 1%, respectively.

As part of the preliminary tests, a delta homogeneity test suggested by Pesaran and Yamagata (2008) is applied and the result is presented in Table 6. Accordingly, the null hypothesis that the slope coefficients are homogeneous for Model 1 is rejected. On the other hand, the null hypothesis is not rejected for Model 2. This result shows that the slope coefficients are homogeneous.

Furthermore, the panel unit root test is performed using separate tests for Model 1 and Model 2. The purpose is to check the integrating properties of the variables employed in this study. As reported in Table 7 (a), the CADF test is applied for model 1, which controls for cross-sectional dependence and heterogeneous panels, and Levin-Lin-Chu panel unit root test proposed by Levin et al. (2002) for model 2, which is most suitable for second generation analysis with homogeneous panels (see Table 7b). From Table 7(a), it can be seen that, in the CADF unit root tests, the null hypothesis points to the existence of a unit root, while the alternative hypothesis is that there is no unit root and the series is stationary. Accordingly, all variables became stationary after taking the first difference except urban population which is stationary at level. However, as reported in Table 7(b), the Levin-Lin-Chu panel unit root test results for Model 2 suggest that, except for raw material productivity for green growth and economic complexity, all other series became stationary after the first difference is taken.

Table 8 presents Westerlund (2007) cointegration test results. The null hypothesis of the test in question is that there is no long-term relationship (cointegration) between the variables, while the alternative hypothesis states that there is a long-term relationship (cointegration). As seen in Table 8, the null hypothesis is rejected. This suggests that the sample provides us with results that there is an existence of a long-run relationship (cointegration) between the variables used in this study.

Table 9 presents the DOLSMG test results, which give reliable results in terms of cross-section dependence and slope heterogeneity proposed by Pedroni (2001). According to the t-statistics obtained, the effects of GDP, UP, and OIL are statistically significant except for the GAS variable. Given that Model 1 and Model 2 are in linear-logarithmic form, the parameter interpretation is provided in this direction. Accordingly, a 1% increase in GDP reduces RMP by 0.03. Also, a 1 unit increase in UP decreases RMP by −0.56, while a 1 unit increase in OIL reduces RMP by 1.01. For Model 2, the PDOLS estimator proposed by Pedroni (2001), which takes into account both cross-sectional dependence and slope homogeneity, is employed. Accordingly, the RENE variable is statistically significant. Thus, a 1% increase in RENE increases RMP by 0.005. Although ECI and ET variables were also found to increase RMP, these results were not statistically significant.

Two separate panel causality tests for Model 1 and Model 2 are

Table 6
Testing for slope heterogeneity.

Model 1			Model 2		
Delta		p-value	Delta		p-value
3.775		0.000*	1.162		0.245
Adj.	4.304	0.000*	Adj.	1.293	0.196

Note. The values in the table give the probability values. * Indicates that the null hypothesis was rejected at 1%.

Table 7a
CADF panel unit root test results for Model 1.

Variable	t-bar	CV10	CV5	CV1	Z[t-bar]	P-value
rmp	−2.18	−2.21	−2.33	−2.57	−0.87	0.19
Δ*rmp*	−3.796	−2.21	−2.33	−2.57	−4.20	0.00*
gas	−1.627	−2.21	−2.33	−2.57	0.27	0.61
Δ*gas*	−3.64	−2.21	−2.33	−2.57	−3.88	0.00*
oil	−2.449	−2.21	−2.33	−2.57	−1.42	0.08***
Δ*oil*	−4.164	−2.21	−2.33	−2.57	−4.96	0.00*
up	−3.651	−2.21	−2.33	−2.57	−4.96	0.00*
gdp	−0.937	−2.21	−2.33	−2.57	1.70	0.96
Δ*gdp*	−3.836	−2.21	−2.33	−2.57	−4.28	0.00*

Note. The values in the table give the probability values. * and *** indicate that the null hypothesis was rejected at 10% and 1%, respectively.

Table 7b
Levin et al. (2002) panel unit root test results for Model 2.

Variable		Statistic	P-value
rmp	Unadjusted t	−4.22	0.02
	Adjusted t*	−1.99	
lnet	Unadjusted t	−2.52	0.20
	Adjusted t*	−0.82	
Δln *et*	Unadjusted t	−13.17	0.00
	Adjusted t*	−10.88	
eci	Unadjusted t	−4.88	0.00
	Adjusted t*	−2.47	
lnrene	Unadjusted t	−2.08	0.10
	Adjusted t*	−1.27	
Δ*lnrene*	Unadjusted t	−13.23	0.00
	Adjusted t*	−11.14	

Note. Akaike information criterion was selected.

Table 8
Westerlund (2007) Cointegration test results.

Model 1				Model 2			
Statistic	Value	Z-value	P-value	Statistic	Value	Z-value	P-value
Gt	−2.98	−1.95	0.03**	Gt	−2.38	−1.30	0.10
Ga	−3.76	1.72	0.96	Ga	−6.25	0.50	0.69
Pt	−6.53	−2.60	0.01**	Pt	−4.89	−1.72	0.04**
Pa	−3.60	0.69	0.76	Pa	−6.93	−0.84	0.20

Note. ** indicates that the null hypothesis was rejected at 10% and 1%, respectively.

Table 9
DOLSMG and PDOLS test results.

Panel A. DOLSMG results for Model 1		
Variable	Coefficients	t-stat
lngdp	−3.14*	4.32
up	−0.561*	−2.56
oil	−1.01*	−7.76
gas	8.81	−1.75
Panel B. PDOLS results for Model 2		
Variable	Coefficients	t-stat
lnrene	0.54*	4.47
eci	0.09	0.39
lnet	0.03	0.34
R^2	0.89	
$\overline{R}^2$	0.85	

Note. Panel Method: Pooled estimation; Lags specification: AIC criterion, Cointegrating equation deterministic: C, Long-run variance: Bartlett Kernel, Newey-West fixed bandwith for PDOLS method.

performed. This is because Model 1 is a heterogeneous panel and Model 2 is a homogeneous panel. Therefore, Model 1 is tested by using the Panel Fisher causality test. Table 10 presents Panel Fisher causality test results for Model 1. Accordingly, there is a unidirectional causality relationship from GDP to RMP for Norway. There is unidirectional causality from GAS to RMP for Denmark and Finland. Finally, there is a one-way causality relationship from OIL to RMP for Denmark. Furthermore, Table 11 illustrates the panel Granger causality test results for Model 2. As reported in the Table, the results prove the existence of a bidirectional causality relationship between ET and RMP variables.

Table 11
Panel Granger causality test results for Model 2.

Null Hypothesis	F-statistic	p-val.
Δlnet≠>rmp	3.07064	0.051***
rmp≠>Δlnert	2.74073	0.070***
eci≠>rmp	0.74172	0.479
rmp≠>eci	1.11913	0.331
Δlnrene≠>rmp	0.85955	0.426
rmp≠>Δlnrene	0.03171	0.968

Note. Lags = 2, Stacked test (common coefficents).

4. Results

The results of the DOLSMG suggest that an increase in GDP, UPOP and OIL would have a deteriorating effect on raw material productivity for green growth. This means that the pressure of accelerating economic growth resulting from economic expansionary policies deplete the raw material productivity for achieving green growth in the Nordic region. This finding is contrary to Fernández-Herrero and Duro (2019) and Kassouri et al. (2021) that found evidence in support of the positive effect of economic growth on domestic material consumption in Nordic countries as demonstrated in the current case. The difference in the result can be traceable to different measurements of dependent variable. While these studies are basically concerned with the total domestic materials consumed, our study is concerned with raw materials productivity for achieving green growth. Similarly, the negative impact of urban population on raw material productivity for green growth suggests that population density is an issue draining raw materials productivity in Nordic countries. It means that increase in urbanization hampers the ambitious environmental sustainability drive of the region through declining in raw material use and material efficiency for green growth. This, by implication, affect energy efficiency and low-carbon neutrality target. Furthermore, the negative effect of OIL indicates that the demand for oil consumption reduces raw materials productivity for green growth in the Nordic region. Therefore, this finding is congenial to Fernández-Herrero and Duro (2019).

Moreover, having controlled for both CSD and slope homogeneity, it is found that increase in renewable energy consumption stimulates raw material productivity for green growth. The Nordic countries, over the years, have been committed to ambitious climate goals of energy efficiency and low-carbon nations. To this extent, as a region, Nordic countries have launched a research and innovation program to facilitate funding of cooperative research and innovation to achieve these goals in the Nordic region. Specifically, the cooperative research and innovation in the Nordic countries have funded a wide range of projects in solar energy, bio-refining, wind energy, and efficient use of available resources from food production, mining, low-carbon approaches to metallurgy, as well as innovative methods of using biomass resources etc. All these generally have implications for stimulating raw material productivity needed for transition toward the path of green growth and sustainable development in the region.

For policy crafting, in Norway, GDP can predict raw material productivity. The implication of this result is that the previous value of economic growth has a predictive power for the level of raw material use. Therefore, green growth policies improve the level of material productivity in Norway. This finding is consistent with Usman et al. (2022) who found a unidirectional causality, flowing from economic growth the material production in EU countries. The result also found that the previous values of gas significantly predict raw material productivity in both Denmark and Finland. In addition, oil consumption has a predictive power for raw material productivity in Denmark. The implication of the results of our studies is that with exception of Norway which is a dominant oil exporting country among the Nordic countries, the level of raw material productivity is predicted by the change in OIL and Gas. This explains the importance of fuels in the determination of the material use and material efficiency in these countries. Therefore, these findings can possibly explain the question of inequalities of material productivity among Nordic countries as put forward by Fernández-Herrero and Duro (2019). For example, our findings could imply that countries with less consumption of fuel may possible have greater material productivity than countries with more level of fuel consumption.

5. Implications

The result of this investigation further illuminates that resource efficiency. Given the Nordic's economic development, there should be more scrutiny of the countries' economic agents especially of inputs related to direct material. Specifically, product standards should not only be a template to achieve energy and environmental sustainability, industrial and business operations should be driven by innovative processes that thrives on optimizing output with minimal direct material input. Additionally, there should be improved dedication to the implementation of socioeconomic measures that tends to spur the development and attractiveness of rural, semi-urban, and suburbs as a way of

Table 10
Panel Fisher Causality test results for Model 1.

Null Hypothesis: gdp≠>rmp				Null Hypothesis: gas≠>rmp			
Country	Lag	Wald	p-val.	Country	Lag	Wald	p-val.
Denmark	1	0.649	0.421	Denmark	1	5.745	0.017**
Finland	1	1.445	0.229	Finland	1	2.923	0.087***
Norway	1	2.912	0.088***	Norway	1	2.345	0.126
Sweden	1	1.333	0.248	Sweden	1	0.039	0.843
Null Hypothesis: oil≠>rmp				**Null Hypothesis: upop≠>rmp**			
Country	Lag	Wald	p-val.	Country	Lag	Wald	p-val.
Denmark	2	5.434	0.066***	Denmark	2	2.953	0.228
Finland	1	2.064	0.151	Finland	2	3.079	0.214
Norway	1	1.628	0.202	Norway	2	1.06	0.589
Sweden	1	0.206	0.650	Sweden	2	1.081	0.583

Note. Number of Bootstrap replications is 10.000. Akaike information criterion is used for test process. **, and *** indicate that the null hypothesis was rejected at 10%, and 5%, respectively.

decentralizing and decongesting urban population. Although the Nordic countries have continued to improve in the share of renewable energy in their total energy mix, greater shift toward alternative energy sources through energy financing and investment should no doubt improve material and resource efficiency in the region.

6. Conclusions

This study examined the factors affecting material productivity of the Nordic countries (except Iceland) over the period 1995–2020. While looking at the different roles of economic complexity and its outlook, the effects of technologies associated with environment and urban population alongside the conventional and unconventional energy forms were also considered. By employing requisite empirical techniques especially that accounts for drawbacks in panel estimations such as the cross-sectional dependency and slope homogeneity, interesting and useful results are revealed. For the purpose of the investigation, two separate models vis-à-vis heterogeneous and homogeneous panels were conceived such that DOLSMG and PDOLS are suitably deployed for the coefficient estimation.

Notable from the DOLSMG results, the prospect for green productivity in the Nordic countries is found to be significantly hampered by the increase in economic growth, urban population, and the use of oil energy. While this result is seemingly undesirable, the PDOLS result revealed that renewable energy is key indicator that significantly spur resource productivity in the panel of Nordic countries. Contrarily, technologies associated with environment and economic complexity are inconsequential in driving material productivity. Moreover, the Emirmahmutoglu and Kose (2011) causality approach provides country-specific results such that Granger causality from economic growth to material productivity is only significant for Finland, Granger causality from oil energy to material productivity is only significant in Denmark, and the Granger causality from natural gas to material productivity is statistically significant in Denmark and Finland. While the limitation of the current study such as the lack sectoral dimension of the result can be improved upon in subsequent study, the above-mentioned result provides some relevant policy directives.

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.

Appendix

Table 1
Definition of variables

Variable	Code	Unit	Source
Raw material Productivity for green growth	Rmp	USD/KG	Database of Global Material Flows (GMF)
Economic indicator	Gdp	Constant 2015 USD	GMF
Urbanization	Up	Percentage of population	World Bank
Technologies related to the environment	Et	Percentage of technologies	Global Material Flows Database
Economic complexity	Eci	Index	OEC. world
Renewable energy consumption	Rene	Tonne of oil equivalent	OECD
Oil	Oil	Oil energy consumption in Exajoules	The British Petroleum
Gas	Gas	Gas consumption, Exajoules	The British Petroleum

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