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Drivers of sustainable natural capital, forest capital, and green growth in Sweden: Rise and fall scenario of material productivity

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ABSTRACT

Given Sweden's impressive performance on green growth among the European Union countries, this study is focuses on examining the responses of green growth, sustainable natural capital, sustainable forest capital, and carbon footprint to environmental-related innovation and material productivity while employing population to control for unobserved forces. By employing the dataset that spans over 1970–2019 alongside using suitable econometric approaches, the short- and long-run relationships alongside the Granger causality evidence are provided. The revelation from the result shows that environmental-related innovation promotes sustainable natural capital (by elasticity of ~ 0.04), promotes sustainable forest capital (by elasticity of ~ 0.13), improves green growth (by elasticity of ~ 0.01), but spur carbon footpint (by elasticity of ~ 0.01) especially in the long-run. Importantly, the investigation further reveals that material productivity exhibits an inverted U-shaped relationship with sustainable natural capital, sustainable forest capital, and carbon emission, thus affirming the validity of material productivity Kuznets curve (MPKC) i.e., rise and fall scenario of material productivity. Meanwhile, while population produces desirable carbon emission and green growth outcomes, it hampers both sustainable natural capital and sustainable forest capital especially in the long run. Given these results, relevant and implementable policy guidelines are highlighted for policy makers and other stakeholders in Sweden.

1. Introduction

In the last years, the concept of sustainable ecological system, environmental sustainability, sustainable development, and green economy have received growing attention from researchers (Celik and Alola, 2023; Nosheen et al., 2021; Fernandes et al., 2020; Guziana, 2011), and from private and public institutions. Although still largely contentious, green growth and its associated terms form the assumption that a nation can enhance economic growth/development without necessarily increasing environmental degradation, or averting climate change challenges in the process. As such, the proponents of green economy advocates that enhancing growth/development, decoupling of economic growth from available resource utilization and negative environmental effects is inevitable. One major driver of the green economy is the transition towards sustainable energy systems arising from environmental-related policy drive. Arguably, sound implementation of these policies could lead to employment opportunities in areas, such as, sustainable forestry, renewable energy, and green agriculture. However, it is paramount to note that, green growth is synonymous with and not a replacement for sustainable development, as it provides a flexible and practical means for achieving tangible, measurable progress across its environmental and economic supports, while taking into consideration, social costs of greening the economic growth dynamic of nations (https://www.oecd.org/greengrowth/whatisgreengrowthandhowcanithelpdeliversustainabledevelopment.htm).

Sweden's case is interesting , when it comes to a nation that has been successful in the quest for green and sustainable economy (Dual Citizen, 2022). According to the Dual Citizen (2022) latest report, Sweden has some of the most striving green economy strategies globally. Introduced in 1991, Sweden has the first and most all-inclusive carbon tax globally; the nation subsidized its electric vehicles since 2006; attained its 2020 target of achieving 50 per cent renewable electricity target in 2012, eight years early than projected. In response to COVID-19 pandemic, at a time when nations are indecisive in their environmental pledges, Sweden intensified efforts on the green evolution by directing stimulus payments to energy efficiency, decarbonization, environmental restoration and green jobs among others (European Commission, 2022). Additionally, economic, and financial bailouts to industries that are

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generating excessive carbon emissions came with environmental conditions attached; numerous non-renewables (fossil fuel) energy sources subsidies decompressed, while new loan applications extended only to green businesses. Globally, Sweden is the eleventh-highest gross domestic product (GDP) per capita nation, coupled with an export-orientated economy grounded on high-valued skill in telecoms, engineering, pharmaceuticals and automobiles. However, GDP per capita might be a poor predictor of a nation environmental drive: Qatar and the United States top the GDP per capita Table, but these nations are not among world leader in terms of green economy.

Besides, the impact of environmental-related innovation on the country's drive for a green growth cannot be downplayed. Environmental innovation *hence eco-innovation* is a precise type of innovation directed at decreasing the effect of climate change on the natural environment, promote green growth and enhance overall sustainable development. Some of the advanced countries, especially the Europe Union (EU) have recognized the importance of eco-innovation, therefore have invested substantial financial resources to promote environmental innovation in their respective countries and regions. In recent time, governments of these advanced nations, including the EU, have intensified efforts to promote greener innovation and greener growth. The EU, especially member country like Sweden have laid down strategies to facilitate structural transformation with emphasis on environmental sustainability through series of measures that include the European Green Deal (European Commission, 2023).

For Sweden, the country specifically aims to remain competitive, when it comes to environmental innovation that promote an all-inclusive societal, economic, technological, and organizational structure. Eco-innovation is a means to provide new opportunities such as employment, structural transformation, and economic growth to facilitate smooth transition from non-renewable energy-driven economy to a more sustainable green economy, that prioritize utilization of renewable and more sustainable resources. According to Yamano and Guilhoto (2019), Grillitsch and Hansen (2019), Long et al. (2017) and Lin and Xu (2018) eco-innovation policies are directed towards stimulating development, and most specifically on climate change, thus a driver of green economy. Green growth refers to a form of production that comprises inventive and innovative means of production, that are not harmful to the environment. Green growth policies are not directed, only to meet the growing demand for goods and services, but also towards the promotion of environmental-friendly production methods especially through material resource efficiency vis-à-vis material productivity (MP) (Nosheen et al., 2021; Grillitsch and Hansen, 2019; Montt et al., 2018; Alola & Adebayo, 2023).

In the last decades, the rate at which natural resources are used has increased, specifically, since the industrial revolution era, coupled with the growth of material productivity. Thus, it is expedient to take cognizance of the rate (intensity) at which natural resources are being used in production activities (production of both intermediate and finished goods). As part of the debate, resources utilization vis-a-vis efficiency of raw materials has received growing attention, as a result of its crucial role in production processes, and its impact on the environment (Bahn-Walkowiak and Steger, 2015; UNEP IRP, 2011). In the context of the EU, material productivity intensity takes a center stage in policymaking. One aspect of the material strategies in this region focuses on strategic role of material as inputs in production function (EC, 2008; EC, 2010), and the other side of material strategies focus on its impact on the environment (EC, 2011; EC, 2015). Specifically, the EU material strategies considered both the economic and environmental objectives in policy decisions. In the region, strategies are built with the aims to enhance material productivity of businesses, which is argued to have increased business competitiveness, while substantial resources have been invested in projects expecting to advance material productivity. For example, between the periods 2005–2014, the European Investment Bank (EIB, 2015) invested about 14.9 billion Euro, in material resource efficiency and associated areas while between the periods 2006–2015, the European Bank for Reconstruction and Development (EBRD, 2015) invested about 18.3 billion Euro, respectively. These policies are geared towards enhancing green growth in products and production processes by firms.

However, the implementation of material resource efficiency measure has not been shown to have a direct influence on the world's population dynamics which is anticipated to rise to about 11 billion by 2100. It is argued and anticipated that population explosion will take place in the lower middle income and low-income countries of the world. Going by the United Nations (UN) population projections, and reflecting on the past population growth record, it is improbable that the increase in the world population for the next four decades will be considerably slower or faster than expected. Incessant increase in population amplifies the damaging effect of economic activities on the environment; however, the increase in income per capita is perceived to be more crucial than population explosion in stimulating the rise in production and consumption of goods and services. Nations with the higher per capita consumption of emissions and material resources are usually those with high per capita income, and not those nations where the population is mounting swiftly (UN, 2019).

Considering the above motivation, the current study empirically examines whether environmental-related innovation, material productivity intensity, and population are significant drivers of load capacity factors of natural capital (comprising of crop, fishing, forest, and grazing), load capacity factors of forest capital, carbon emission, and carbon productivity (proxy for green growth policy) for the case of Sweden. By building on this objective, the case of Sweden is considered for the investigation especially because of impressive record of the country as the top green growth performer among the EU countries (Green Growth Index, 2022). Additionally, Sweden has reportedly decreased the use of fertilizer by a significant proportion, thus improving the country's sustainable land use among several countries across the globe. This underlined perspective of the investigation accounts for the novelty of study, thus providing a significant contribution to the existing literature. Retrospectively, the econometric approach employed in the investigation provides the short- and long-run response of the sustainable natural capital, sustainable forest capital, environmental quality vis-à-vis carbon emission, and green growth to changes in environmental-related innovation, material productivity, and alongside population. Furthermore, the validity of material productivity Kuznets curve (MPKC) hypothesis i.e., rise and fall of material productivity is investigated. Moreover, the aggregation of evidence provided by this investigation should provide concrete policy dimension for Sweden.

There is other important part of this study, and such is structured accordingly. In section 2, related studies are discussed while the data description alongside the empirical methods are detailed in section 3. Sections 4 and 5 are reserved for the discussion of the results and conclusion with policy highlighting respectively.

2. Literature review

This section begins with the brief discussion of the existing literature as it relates with green growth policy aspects. The section focuses on environmental-related innovation and material productivity as it relates with green growth potential.

2.1. Environmental-related innovation and green growth

The empirical study of Solow (1956) growth model laid the foundation for the technology-economic growth model. In the study, Solow (1956) examined the long-run nexus between innovation (technology) and economic growth as it emphasized the significant impact of technology (innovation) on economic growth. Overtime, this subject has gained growing attention among researchers, thus lending voices in support with Solow findings (Chien et al., 2021a; Fernandes et al., 2021; Ferreira et al., 2020; Ferreira et al., 2019; Crespi et al., 2016; Rozkrut, 2014; Bayarcelik and Taşel, 2012; Machiba, 2011; Hasan and Tucci, 2010; Wong et al., 2005; Freeman, 2002; Grossman and Helpman, 1993; Segerstrom, 1991). Also motioned, the study of Teece (1986) advocates for profiting from innovation technique (PFI). According to Teece (1986), the PFI approach stems from the features of environmental factors, appropriability system, excluding market structure and the firm, which measures the capacity to capture the gains made through a specified innovation.

Additionally, Guoyou et al. (2013) is of the opinions that notes that the administration of environmental innovation is an essential tool for the government and firms (entrepreneur) to achieve significant outcomes when it comes to environmental protection and enhancing sustainability. To them, entrepreneurs are not adequately informed on how to manage the environment. This is due to the fact that, government prioritized economic gains as a means of reducing poverty over environmental sustainability. This has led to increased environmental degradation because of there is no efficient policy in place. Ben Amara and Chen (2020) argued that, government and policymakers have hit a brick wall in achieving desired goals of environmental protection and poverty reduction simultaneously, as they have not been able to enact meaningful policies and reforms to coordinate the interests of several stakeholders. Rennings et al. (2004) reported that, green goods innovations would lead to job creation and subsequently economic expansion. Fankhaeser et al. (2008) in their analysis argued that, there are positive impacts to reducing environmental degradation via greenhouse gases emission mitigation approaches that includes; increased innovation, employment opportunities and hence economic expansion (growth). Based on these findings, there exist a connection between employment and environmental innovations.

For environmental innovation to drive green growth, government needs to enact policies that delink environmental degradation from economic growth, through reduction in the unit of resources used (relative decoupling) while targeting absolute (absolute decoupling) reduction in the use of materials and energy use (Machiba, 2011; Kijek and Kasztelan, 2013; Rozkrut, 2014). To Faucheux and Nicolaï (2011), environmental innovation is designed to reconcile green growth and information technology development that enforces specific change towards sustainable development, which includes, organizational, social, technological and institutional innovations. Similarly, Crespi et al. (2016) on the relationship between environmental innovations, green growth, and sustainable transitions, emphasized the concept of Green Transition System by proposing the activation of adaptive mechanism and learning by involving stakeholders, private agents, among others involved in the transition process. However, Horbach et al. (2013) argued that, green goods innovations does not necessarily generate employment opportunities, but green process innovations does, specifically for those that generate energy and material savings. Chien et al. (2021a) found a negative between eco-innovation and carbon emissions, thus positioning that eco-innovation promotes green economy. Despite all these debates, we are of the opinion that, increased environmental innovations would enhance green growth, and create a series of changes in employment, demand, supply, and resource efficiency that would enhance economic expansion.

Within this dimension, Ben Amara and Chen (2020) argued that individuals and business operators should take into consideration the impact of their consumption and production activities on the environment by integrating sustainable green technologies and/or innovation approaches as a remedy to the modern environmental concerns. The study further notes that, for governments and policymakers to be efficient and economically viable with the adoption of environmental innovation policies, it must put in place adequate and sufficient energy policies, regulations, and instruments to reduce the degradation of natural environment. Following this perspective, Balcilar et al. (2023) investigated whether the operational activities of multinational corporations through foreign direct investment (FDI) and natural resource rent affect environmental quality in selected African states during the period 1990 to 2017. By using System Generalized Method of Moments (SYS-GMM) and Method of Moments Quantile regression (MMQR), the investigation reveals that operational activities of multinational corporations as influenced by natural resource rent improves environmental degradation but not at all levels of natural resource rent exploration. Additionally, the result explains that both increase in FDI in low natural resource rent economy and increase in resource rent in low FDI states all yields environmental degradation.

2.2. Material productivity intensity and green growth

Material productivity (MP), like labor productivity, is the ratio between the output and the inputs (material) of a production processes (OECD, 2007). To Dahlström and Ekins (2005) and Syverson (2011), material productivity offers necessary information on how outputs are produced from material inputs with the following computation expression:

$MP_{i,t}= \frac{Output(Y)_{i,t}}{Mateialinput(M)_{i,t}}$ .here, i stand for the firms, while t is the time dimension. Material productivity as a consistent measure of output productivity have been adopted and used by global establishments (UNEP IRP, 2011; 2014), by researchers (Flachenecker and Kornejew, 2019; Wiedmann et al., 2015; Steinberger and Krausmann, 2011; Bruyn et al., 2009), and in empirical studies, and policymaking documents (Bahn-Walkowiak and Steger, 2015; Hinterberger et al., 2003) respectively. While material resource efficiency is measured in term of material resource productivity, it is also measured in term of material resources intensity. However, material resources intensity could measure material resource efficiency based on the derived economic value depending on the usage of physical unit of these resources in a nation.

A modern economy necessitates extensive usage of material for consumption and production (Fernández-Herrero and Duro, 2019). There are series of subsequent environmental effects in terms of natural resources depletion, biodiversity reduction, waste and emissions, industrial pollution and hence climate change (UNEP, 2006; Alola et al., 2022). Contrarily, scarcity of natural resources also leads to conflict and struggle for resources control, thus hindering overall economic growth and development (Muradian and Martinez-Alier, 2001). The situation is not necessarily different when relating the availability of material resources to population growth rate. Future availability of material resources could be unsustainable, when considering the increase in the living standards of existing and projected future populations. For instance, Schandl et al. (2016) argues that by 2050, about 180 billion tons of material would be required annually to sustain human lives, and this is three (3) times more than what is presently obtainable. Evidently, as investigated by Usman et al. (2020a) and Usman et al. (2020b), renewable energy utilization and biocapacity as critical components of natural capital, and alongside financial development and globalization are significant drivers of environmental sustainability.

Fischer and O'Brien (2012) argue that, enhancing material productivity could be the outcome of environmental innovation, thus arguably contribute positive impact on business and economic achievement . Thus, efficient material productivity growths can lead to increase in labour productivity (Hashi and Stojčić, 2013), enhance export activity (Czarnitzki and Wastyn, 2010; Lachenmaier and Wößmann, 2006), incentivize future innovations in a virtuous cycle (Meyer, 2011), innovative bustle which could surge the market stake (EEA, 2011). It substantially minimizes environmental degradation as businesses and firms advanced in production processes (Hart, 1995) all of which is positively associated with green growth policy. In addition, material productivity enhances employment, productivity, and innovation activity in firms, networks, clusters, and economic activity (EC, 2014; Walz, 2011; Ecorys, 2011; Meyer, 2011; Distelkamp et al., 2010). Moreover, by examining the case of 23 selected Organisation for Economic Co-operation and Development (OECD) over the period 1990–2017, Balcilar et al. (2022) deployed the MMQR approach in establishing the economic impacts of green energy consumption and investment. Specifically, the study reveals that green energy consumption and investment in green energy exerts heterogeneous and positive impact on per capita economic growth with a stronger impact established at the lower quantiles. Meanwhile, by using the same empirical approach for the G7 countries over the period 1990–2017, Usman (2022) found that expenditure on green energy technologies and renewable energy utilization also exerts heterogeneous but positive impact on carbon emissions.

3. Data description and methods

The study implements dataset that comprises of carbon dioxide emission i.e C (measured in million tonnes of carbon dioxide), population i.e POP (millions of people), diffusion of environmental-related innovations i.e ERI (measured as percentage of inventions worldwide), material productivity i.e MPROD (estimated as GDP/domestic material consumption and measured as USD/Kg), and gross domestic product i.e (measured in 2015 constant USD). Other variables of interests are computed as follows:

Sustainable natural capital (i.e SNC) $= \frac{\text{Total biocapacity (including crop, fishing, forest, and grazing)}}{\text{Total ecological footprint (including crop, fishing, forest, and grazing)}}$ (measured in global hectares);

Sustainable forest capital (i.e SFC) $= \frac{\text{Forestry biocapacity}}{\text{Forestry Ecological footprint}}$ (measured in global hectares);

Green growth (GGDP) $= \frac{\text{GDP}}{\text{Carbon dioxide emission}}$ i.e it measures the rate of decoupling output from environmental degradation (USD/ million tonnes of carbon dioxide) which also implies decarbonization rate.

Given the above expressions, sustainable natural and forest capital are expectedly attainable with ↑SNC and ↑SFC while unsustainable natural and forest capital arises from ↓SNC and ↓SFC. Thus, sustainable natural and forest capital corresponds to the elasticity of SNC and SFC with respect to MPROD > 0 (i. e $\frac{SNC/SFC}{\text{MPROD}} > 0$) and unsustainable natural and forest capital corresponds to the elasticity of SNC and SFC with respect to $\text{MPROD}^2 < 0$ (i. e $\frac{SNC/SFC}{\text{MPROD2}} < 0$) as the reverse of the expressions expectedly holds. Contrarily, the elasticity of carbon emission (C) with respect to MPROD and MPROD^2 expectedly leads to unstainable environmental quality and sustainable environmental quality when $\frac{C}{\text{MPROD}} >$ 0 and $\frac{C}{\text{MPROD2}} < 0$ respectively (and the reverse also expectedly holds).

The sources of the data are the World Bank database for GDP and population, OECD for diffusion of environmental-related innovations, global material flow database of the United Nations Environment Programme for material productivity while global footprint network database is the source of biocapacity and ecological footprint components. As indicated in Table 1, the variation in the ratio of total biocapacity to total ecological footprint is lowest followed by the variation in material productivity. In term of correlation evidence, green growth and population exhibits negative association with all of C, SNC, and SFC (but only statistically significant with C and SNC) while material productivity only shows negative and significant correlation with carbon emission (see Table 2). The dataset covers the period 1970–2019.

3.1. Method

Before performing the empirical estimation of the econometric model, series of necessary pre-investigations such as the correlation relationship, the stationarity, and cointegration tests were carried out. Although the results of the aforementioned tests support the justification, some of the results are not provided here because of space limitation.

3.1.1. Empirical model

The models investigated are from economic and environmental perspectives. For the environmental perspective, the model employed followed the environmental Kuznets curve (EKC) that is derived from the earlier work of Kuznets (2019). Meanwhile, the economic perspective follows the reflection of the baseline traditional economic growth theory detailed in Solow (1956) and the production theory on efficiency evaluation as explained in the works of Debreu (1951) and Shephard (2015). While the EKC framework is conceived in three different expressions as.

$C = f$ (ERI, POP, MPROD, MPROD^2).

$SNC = f$ (ERI, POP, MPROD, MPROD^2).

$SFC = f$ (ERI, POP, MPROD, MPROD^2).the economic framework which defines carbon productivity i.e decarbonation rate models green growth as.

$GGDP = f$ (ERI, POP, MPROD).

Therefore, while the above models are re-parametrized by using the logarithmic transformations, the appropriate econometric tools are applied to provide relevant results. In this case, both coefficient estimation and Granger causality approaches are employed. To estimate the coefficient of the relationships, the autoregressive distributed lag (ARDL) approach by Pesaran et al. (2001) is employed to reveal the short- and long-run relationships. This approach reveals the short-run bound testing estimation alongside the adjustment parameter of the short- and long-run relationships. The approach is typically advantageous for this investigation because the technique is not strictly restricted to a particular order of integration of the variables (provided no variable has $I(2)$). Additionally, the techniques provide pathway to estimate relevant post estimation diagnostic tests. Moreover, the step-by-step approach of this technique is well-documented in the literature, thus these procedures are not repeated here because of space constraint. Meanwhile, to compliment the result of the coefficient estimation, Breitung and Candelon (2006) Granger causality approach is applied to provide robustness via a frequency-related inference.

4. Discussion of results

4.1. Drivers of ecological biocapacities

The results of the short- and long-run empirical estimations of the aforementioned four models are displayed in Table 3. For natural and forest capital, the investigation reveals that material productivity in both short- and long-run drive toward achieving sustainability. Specifically, SNC and SFC respond to material productivity with long-run

Table 1
Descriptive statistics of the variables.

Statistics	C	SFC	SNC	GGDP	ERI	POP	MPROD
Mean	68.993	5.896	1.651	5.55E + 09	3.130	8,821,694	2.294
Median	64.229	5.178	1.654	4.79E + 09	0.850	8,817,327	2.405
Maximum	114.444	19.419	1.932	1.21E + 10	16.700	10,036,379	2.839
Minimum	44.699	2.158	1.248	2.02E + 09	0.160	8,054,916	1.416
Std. Dev.	17.479	2.659	0.164	2.98E + 09	5.002	562537.9	0.370
Skewness	0.636	2.933	−0.233	0.703272	1.796	0.589626	−0.777
Kurtosis	2.556	14.869	2.358	2.389478	4.749	2.288464	2.731

Note: SNC is sustainable natural capital (total load capacity factor), SFC is sustainable forest capital (forest load capacity factor), MPROD is material productivity, POP is population, GGDP is green growth, C is carbon emission, and ERI is diffusion of environmental-related innovations.

Table 2
Evidence of correlation among the variables.

Variables	C	SFC	SNC	GGDP	ERI	POP	MPROD
C	1.000						
	———						
SFC	0.118	1.000					
	0.4130	———					
SNC	0.048	0.647	1.000				
	0.7421	0.000	———				
GGDP	−0.887	−0.145	−0.273	1.000			
	0.000	0.317	0.056	———			
ERI	0.723	−0.051	−0.297	−0.607	1.000		
	0.000	0.726	0.037	0.000	———		
POP	−0.874	−0.106	−0.237	0.989	−0.642	1.000	
	0.000	0.465	0.097	0.000	0.000	———	
MPROD	−0.697	0.108	0.383	0.533	−0.851	0.566	1.000
	0.000	0.456	0.006	0.000	0.000	0.000	———

Note: SNC is sustainable natural capital (total load capacity factor), SFC is sustainable forest capital (forest load capacity factor), MPROD is material productivity, POP is population, GGDP is green growth, C is carbon emission, and ERI is diffusion of environmental-related innovations.

Table 3
Short- and long-run drivers of the aspects of green productivity/growth.

Variables	SNC	SFC	C	GGDP
ECT	−0.931[a]	−0.935[a]	−0.470[a]	−0.309[a]
ERI	0.040[c] (0.023[b])	0.134[a] (0.134[a])	0.005 (0.054[a])	0.012 (-0.049[b])
POP	−10.055[b] (-1.045[a])	−0.333[a] (-0.333[b])	−1.187[a] (-2.529[a])	2.058[b] (6.656[a])
MPROD	3.506[b] (3.188[b])	14.993[b] (14.023[b])	2.604[a] (6.211[a])	0.083 (-0.898[c])
$MPROD^2$	−1.817[b] (-1.516[b])	−7.552[b] (-7.338[b])	−1.686[a] (-3.591[a])	
F-Bound Test	12.208[a]	5.402[a]	5.103[a]	4.665[b]
Jarque-Bera	2.443	16.562[a]	1.586	2.974
BGSC LM	0.241	0.544	0.300	0.823
BPG	0.853	0.415	1.734	1.451
OVT	2.293	0.020	0.900	0.464
Stability	Yes	Yes	Yes	Yes

Note: BGSC LM is Breusch-Godfrey serial correlation Lagrange multiplier test, BPG is Breusch-Pagan-Godfrey heteroskedasticity test (with given probability values), OVT is omitted variable test by Ramsey RESET test. Additionally, SNC is sustainable natural capital (total load capacity factor), SFC is sustainable forest capital (forest load capacity factor), MPROD is material productivity, POP is population, GGDP is green growth, C is carbon emission, and ERI is diffusion of environmental-related innovations. Moreover, the short-run coefficient estimation is presented in bracket ().

elasticity of ~ 3.51 and ~ 14.99 respectively while the short-run elasticity is respectively ~ 3.19 and ~ 14.02. This result translates that the country biological capacity improves even at the increase in material productivity (remember material productivity $= \frac{Output(Y)_{i,t}}{Mateialinput(M)_{i,t}}$, i.e efficient use of material input), thus resulting into ecological surplus. Given that increase in material productivity implies that minimal utilization of material input yields optimal output, this result then suggests that natural capital (which include crop, fishing, forest, and grazing) and forest capital in Sweden are not over-utilized over the period of investigation. However, if the material productivity is doubled i.e $MPROD^2$, natural and forest capital both responds with an elastic proportion (a negative relationship ensued) in both short- and long-run. It does show that increase in $MPROD^2$ (doubled proportion of material productivity) endangers the environment giving the declining value of country's biocapacity. This is also an implication that $MPROD^2$ decrease the load capacity factor (LCF) for natural capital and forest in Sweden. Thus, the implication of these two outcomes suggests that there is an inverted U-shaped/rise and fall relationship between sustainable natural and forest capital and material productivity in Sweden. Indicatively, this provides evidence that sustainable natural and forest capital in Sweden becomes a reality only before a certain threshold of material productivity utilization is attained. Beyond such threshold, material productivity will begin to deplete biocapacity of the natural and forest capital, thus triggering ecological deficit of both the natural and forest capital. Although Schandl et al. (2016) pointed the risk of unsustainable material utilization in the long-run especially by 2050, Ecorys (2011) affirms that the efficient use of material resource promotes overall productivity, thus driving green growth.

Moreover, further implementation of the EKC framework, in this case using the carbon emission function reveals that material productivity also exhibit inverted U-shaped relationship with carbon emission. Specifically, the initial stage of material productivity intensification causes rapid carbon emission, thus encumbering environmental quality in both short- and long-run scenarios (result is displayed in Table 3). However, with the intensification of material productivity to a certain threshold, environmental quality begins to improve due to the decline in carbon emission, also in both short- and long-run. Thus, this evidence validates material productivity Kuznets curve. Meanwhile, the impact of population and environmental-related innovations on sustainable natural and forest capital and carbon emission are the same. Specifically, while population diminishes sustainable natural and forest capita, the role of environmental-related innovation is desirable because the statistical evidence suggests that it promotes sustainable natural and forest capital. Unlike the result obtained in the studies of Flachenecker and Kornejew (2019) and Chien et al. (2021b), the result from the current investigation reveals an unexpected observation arising from the impact of environmental-related innovation and population on carbon emission. Although with a small magnitude, the result reveals that environmental-related innovation spur carbon emission in both short- and long-run while population causes a decline in carbon emission. This outcome seemingly aligns with the perspective that while entrepreneurial activities provide employment opportunities, the activities does not necessarily promote environmental sustainability (Guoyou et al., 2013; Ben Amara and Chen, 2020).

Meanwhile, the roles of diffusion of environmental-related innovations (measured as percentage of inventions worldwide) and population in promoting sustainable natural capital and forest alongside the carbon emission and economic growth impacts of ERI and POP are examined (see Table 3). However, the result shows that ERI and POP exert differing impacts on both sustainable natural capital and forest (i.e., LCF for natural capital and forest) in comparison with carbon emissions. For instance, ERI is found to promote sustainable natural capital and forest while causing a surge in carbon emission. On the other hand, POP causes a decline in LCF for natural capital and forest while mitigating carbon emissions. Although these results are unexpected, the explanation of the observation can be intuitively positioned. The estimation of LCF in this case is only based on natural capital and forest capital and not the total component of ecological biocapacity and ecological footprint which naturally accounts for carbon footprint. Therefore, while it seems that ERI deployment in Sweden is appropriate for natural and forest capital, the same deployment is not likely to be environmentally desirable in term of the country's carbon emission reduction strategy. However, these indicators (ERI and POP) promote green growth approach in the country given that a percentage increase in ERI and POP increases green growth in the long run by 0.012% and 2.058% respectively. The positive role of ERI on LCF for natural and forest capita is supported by Liu et al. (2022) for Brazil and Awosusi et al. (2022) for South Africa. Specifically, Liu et al. (2022) found that technological innovation in Brazil improves environmental quality by increasing LCF.

4.2. Drivers of greening growth

As revealed in Table 3, the results show that environmental-related innovation, population, and material productivity all drives carbon productivity i.e the green growth dynamics especially in the long-run in Sweden. However, the short-run impacts of these indicators are not in the same direction. Specifically, while population environmental-related innovation and material productivity hampers green growth in the short -run by elasticities of ~ 0.05 and ~ 0.90 respectively, population spur the potential for green growth by elasticity of ~ 6.66. Although there is no vast literature on the nexus between material productivity and green economy, the study of Flachenecker (2018) for example expresses caution on the perception that increasing material productivity spur the competitiveness of macroeconomic aspects in the European Union. Moreover, in a clearer perspective, Schandl and West (2012) opined that the role of material resource efficiency vis-à-vis material productivity could depend of whether a country is a primary resource provider, advanced manufacturer, or a rapidly industrializing economy.

4.3. Diagnostics and robustness results

In providing a robustness perspective to the above results, the results of the Breitung and Candelon (2006) Granger causality are presented in Fig. 1a & Fig. 1b, Fig. 2a & Fig. 2b), and Fig. 3a & Fig. 3b). The results indicate no evidence of Granger causality from population to green growth (Fig. 1a) while the causality from green growth to population only persists in the long-run (Fig. b). Additionally, there is a long-run causality from material productivity to green growth on in the long-run and the evidence of a reversed relationship does not exist (&b). Lastly, environmental-related innovation Granger causes green growth at long-, medium, and short-term scenarios while the causal relationship only persist in the long-term (Fig. 3a & Fig. 3b). Moreover, in the lower part of Table 3, the bound test suggests statistically significant evidence of short-run relationship while the model is void of autocorrelation and heteroskedasticity setbacks, courtesy of the Breusch-Godfrey serial correlation Lagrange multiplier and the Breusch-Pagan-Godfrey heteroskedasticity tests. Additionally, the estimated models do not suffer

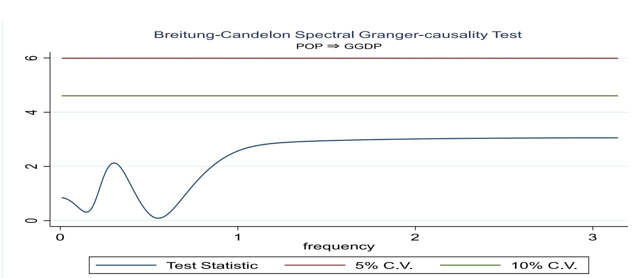

Fig. 1a. Causality from POP to GGDP.

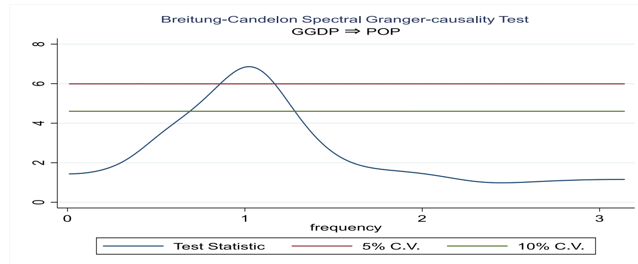

Fig. 1b. Causality from GGDP to POP.

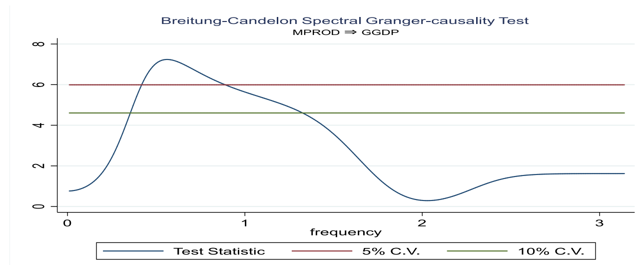

Fig. 2a. Causality from MPROD to GGDP.

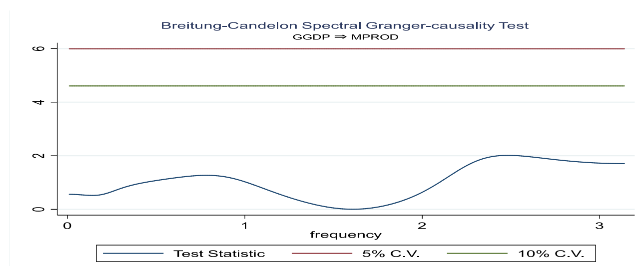

Fig. 2b. Causality from GGDP to MPROD.

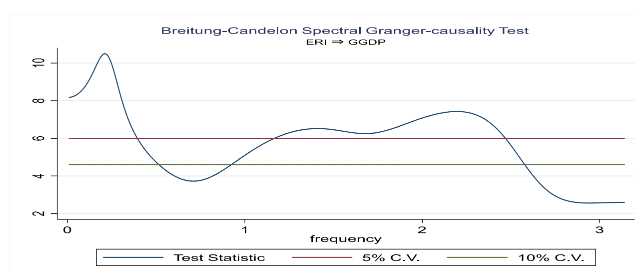

Fig. 3a. Causality from ERI to GGDP.

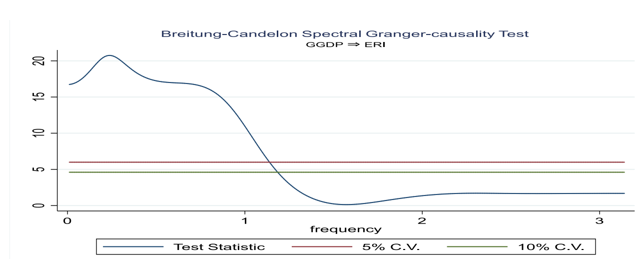

Fig. 3b. Causality from GGDP to ERI t.

from omitted variable bias and the cumulative sum and cumulative sum of squares affirms the stability of the models.

5. Conclusion and policy implication

The current study considered the case of Sweden given the peculiarity of the country on the fronts of circular economy, energy transition, and environmental sustainability amidst its carbon neutral goal. For instance, in Europe, Sweden has the topmost green growth performance (Green Growth Index, 2022), thus providing a good motivation to examine the drivers of green growth, sustainable biocapacities (natural and forest capita), and carbon emission. By using the dataset that covers the period 1970–2019, the short- and long-run relationships of these indicators were examined by implementing the ARDL approach alongside the Breitung and Candelon (2006) Granger causality approach.

The investigation reveals interesting findings. Environmental-related innovation and material productivity are found to positively impact sustainable natural and forest capital, green growth, and carbon emission especially in the long-run. While population is found to hamper sustainable natural and forest capital, and carbon emission in the long-run, increase in population promotes green growth. Moreover, the investigation reveals that a point of inflexion (which is inverted U-shaped) exists in the relationship between material productivity and the ecological indicators i.e carbon emission. sustainable natural capita, and sustainable forest capita. Thus, the validity of MPKC is established in the relationship of material productivity with carbon emission, sustainable natural capital, and sustainable forest capita. As a robustness, the Breitung and Candelon (2006) Granger causality approach provides additional inference. With these indications, appropriate policies are deductible for decision makers and stakeholders.

5.1. Policy implication

Considering the undesirable effect of environmental-related innovation on carbon emission, this suggest that stakeholders could further consider timely review of policy guideline of all innovation activities across the sectors of the economy. For instance, entrepreneurial activities across sectors should be guided by policy instrument that account for environmental sustainability. Considering that the measurement of ERI is based on the diffusion of environmental-related innovations i.e., percentage of inventions worldwide, stricter measure could further be considered as guidelines for both the local development and importation of foreign environmental technologies. The role of citizens participation in environmental accountability and environmental corporate social responsibility could be further encouraged such as to moderate population in delivering a desirable environmental and economic-related effect. Considering the EKC evidence in the investigation as ushered by material productivity, strict policy guideline and adherence to pursue material resource re-use and efficiency, and circular economy at all levels of socioeconomic activities should be further encouraged. In spite this relevant policy implication, the study could be improved upon in the future through a re-examination of the associated limitation(s). For future consideration, sustainable biocapacity of each ecological component i.e crop, fishing, forest, and grazing could be considered rather than exploring the aggregate natural capital. Moreover, there could be replicate of this study framework for other economies especially the Nordics.

CRediT authorship contribution statement

Andrew Adewale Alola: Data curation, Conceptualization, Formal analysis, Methodology, Validation, Writing - original draft. **Seyi Saint Akadiri:** Validation, Writing - original draft, Writing - review & editing.

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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