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Analysing the waste management, industrial and agriculture greenhouse gas emissions of biomass, fossil fuel, and metallic ores utilization in Iceland

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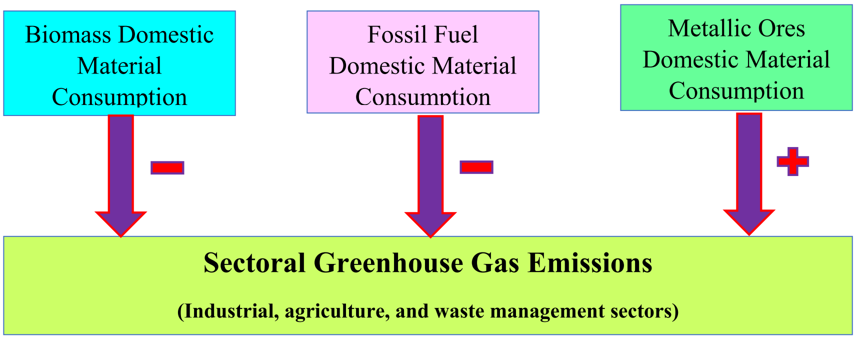
HIGHLIGHTS

- The drivers of sectoral GHG emissions in Iceland are examined.
- Aggregate sector GHG emission is mitigated by biomass and fossil fuel domestic material consumption (DMC).
- Metallic ores DMC spur aggregate sector GHG emission.
- Biomass DMC mitigates agriculture and waste management sectors' GHG emissions.
- Industrial GHG emission is significantly reduced by fossil fuel DMC.

GRAPHICAL ABSTRACT



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ABSTRACT

With Iceland's CAP 2020, the country aims significant improvement in the state of its environment through reduction in greenhouse gas (GHG) emission especially in energy production and small industry, waste management, ships and ports, land transport, and agriculture by 2030. Considering this ambition, this study queries whether the consumptions of domestic materials i.e., DMC (especially metallic ores, biomass, and fossil fuels) exhibit differential impact on (i) aggregated greenhouse gas emissions i.e., GHG, (ii) waste management greenhouse gas emission i.e., WGHG, (ii) industrial greenhouse gas emission i.e., IGHG, and (iv) agriculture greenhouse gas emission i.e., AGHG during the period 1990 to 2019. By using Fourier function approaches, the investigation establishes that metallic ores DMC spur GHG, but biomass and fossil fuel DMC mitigate GHG in the long run. Additionally, biomass DMC mitigates AGHG and WGHG by respective elasticities of 0.04 and 0.025 in the long run. While IGHG is significantly reduced by fossil fuel DMC with elasticity of 0.18 in the long run, the AGHG and WGHG are unaffected by the consumption of fossil fuel domestic materials. Moreover, metallic ores DMC spurs only IGHG by elasticity of ~0.24. The overall evidence shows the need for more stringent material use and resource circularity (especially for metallic ores and fossil fuels) for the country to stay on course of the CAP 2020 and maintain environmental sustainability.

1. Introduction

As obtained in several economies across the globe, economic activities in the transport, agriculture, fisheries, and waste management sectors (as contained in the European Union (EU)'s effort sharing regulation (ESR))

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are largely characterized with high greenhouse gases (GHGs) emissions. Moreover, about 48 % of Iceland's carbon dioxide (CO_2) emission is linked to the country's heavy industrial activities, not including emission of greenhouse gases (GHGs) from forestry and land use (Ministry for the Environment and Natural Resources, 2020). Specifically, Iceland is demonstrating ambitious commitment to reduce GHG emissions by a significant amount in the following five major sectors by 2030: energy production and small industry (to achieve 67 % GHG emission reduction), waste management (to achieve 66 % GHG emission reduction), ships and ports (to achieve 42 % GHG emission reduction), land transport (to achieve 21 % GHG emission reduction), and agriculture (to achieve 5 % GHG emission reduction) (Ministry for the Environment and Natural Resources, 2020). With this drive, Iceland is poised to deliver about 40 % reduction in GHG emission by the set period especially in the ESR-sectors, thus aligning with the country's carbon neutrality by 2040. This commitment is evident in the country's renewed Climate Action Plan (CAP) 2020 that details the 48 actions currently being pursued by the government. Clearly, the country's CAP 2020 which considers the United Nations' Sustainable Development Goals has a significant projection of mitigating GHG emission in the ESR-sectors.

Given this motivation, an interesting dimension and question in line with the country's carbon neutrality target would be that could the country's recent reduction in domestic material consumption (DMC) be sustained and to what degree of impact would that made in the reduction of GHG emissions? Therefore, the objective of this study is constructed along the direction of understanding the GHG emission trend across the main sectors (waste management; industry; agriculture) especially from the perspective of biomass, fossil fuel, and metal ores domestic material consumptions. Clearly, Iceland posits a peculiar scenario among the Nordic states. For instance, although the country is experiencing a significant reduction in DMC in the last few years even before the coronavirus pandemic (decreased by 422 kilotonnes between 2018 and 2019), the per capita DMC as at 2020 (16.7 t per capita) is far above the EU's average of ~14 t per capita (Statistics Iceland, 2021). Moreover, a search of the literature shows no existing study has examined sectoral GHG emissions from the perspective of the DMC, suggesting that this insight is the first for the case of Iceland at least to the best of authors' knowledge. To achieve the abovementioned novel objective, several empirical techniques especially including the Fourier functions for stationarity and autoregressive distributed lag (ARDL) are applied. The technique overcomes the traditional ARDL method that is constrained by size and power. Specifically, when there is more than one explanatory variable, this technique has better power and size characteristics than the ARDL approach. In term of contribution and policy relevance of the investigation, the findings should shed light and open further opportunities for discussion regarding Iceland's CAP 2020 and EU's ESR.

We devise the sections of the study accordingly: relevant studies are discussed in Section 2, the variables are described alongside the empirical protocols and methods in Section 3, the results are discussed in Section 4 while the summary of the study alongside policy insight are documented in Section 5.

2. Literature review

Overuse of natural resources causes ecological damage, which lowers the efficiency of crucial ecosystem services including flood and landslide prevention, thus increasing the likelihood of disasters (natural and man-made) that further deteriorates the ecosystem. Consequently, scholars, policymakers and various organisations have continuously probe potential solution(s) and mitigation strategy to ecological deterioration (Khan et al., 2023; Li et al., 2023; Martin del Campo et al., 2023). Over the years studies on determinants of greenhouse gases (GHGs) emissions have been documented in energy and environmental literature. However, there seems to be inconclusive evidence on the holistic approach to environmental challenges and this could be attributed to the research techniques or approach, variable selection, study timeframe, and the variance in the characteristics of selected case/country or group of country cases being investigated.

For instance, by considering 13 world regions with the implementation of the economic and environmental modelling, Schandl et al. (2016) assessed the feasibility of decoupling economic growth from environmental drawback under the scenarios of carbon emissions, and material and energy utilization. The result of the investigation establishes different scenarios for the Organisation for Economic Co-operation and Development (OECD) economies and the developing economies. Specifically, with little economic growth impact, the OECD economies exhibit the potential to benefit from significant reduction in material utilization and carbon emissions. Meanwhile, China and other developing economies could experience significant economic expansion at a much lower cost to the environment. From the global perspective, there seems to be negligible economic growth and employment boost until 2050 even when more stringent resource efficiency and abatement policies are implemented. Nevertheless, with a properly plan policy measures, dematerialization and decarbonization even with improved human well-being or declining global economic expansion.

The frequency domain causality approach by Breitung and Candelon (2006) was utilized by Sarkodie (2020) to establish the causal responses of environmental factors to domestic material consumption and economic growth. Specifically, metallic ore consumption is not only a significant causative factor of environmental air pollution, but it also predicts renewable energy consumption, economic growth, and income level. From a broader perspective, Alola et al. (2021) examined the role of aggregate domestic material consumption in the trend of GHG emissions among the EU-28 member states over the period 2000–2017. By employing the panel (pooled mean group i.e., PMG) technique of the autoregressive distributed lag (ARDL) alongside the Granger causality approach by Dumitrescu and Hurlin (2012), the investigation points that DMC aggravates GHG emission in the short- and long-run in the panel while renewable energy utilization and per capital income both desirably promotes environmental sustainability especially in the long-run.

However, environmental indicators are largely associated with the disaggregate levels of DMC such as fossil fuels and biomass (Umar et al., 2021) and non-metallic ores (Lin and Ouyang, 2014; Li et al., 2018). Specifically, Umar et al. (2021) employed the long-run estimators including the fully modified and dynamic ordinary least square (FMOLS and DOLS respectively) and canonical correlation regression estimator (CCR) alongside the causality technique documented by Breitung and Candelon (2006) to examine the environmental influence of biomass and fossil energy utilization in the United States of America (USA)'s transport sector during the quarterly period 1981Q1-2019Q4. The (FMOLS, DOLS, and CCR) findings show that real gross domestic product (GDP) and biomass energy utilization mitigate CO_2 emissions in the examined sector, but the emission of CO_2 is spurred by fossil fuel energy consumption. Additionally, with the frequency domain causality approach, GDP, biomass energy utilization, and fossil fuel energy consumption causes CO_2 emissions especially in the long run. Meanwhile, both studies by Lin and Ouyang (2014) and Li et al. (2018) considered the examination of CO_2 emission reduction capability associated with the non-metallic ore sectors. Specifically, by using the Logarithmic Mean Divisia Index (LMDI) technique, Lin and Ouyang (2014) did not only link the non-metallic ore sectors arising from the energy and industrial activities with CO_2 emissions, but the finding also demonstrates that stringent emission policy should attain 188.88 million tonnes equivalent CO_2 reduction as of 2020.

The study of Alola and Adebayo (2023) used the Fourier-based approaches in their investigation on the drivers of GHGs emissions using the dataset from 1990 and 2019. Within the context of Finland, though eco-innovation lessens GHGs emissions, findings reveal that growth trajectory of Finland is not sustainable considering the country's export intensification pathway. Similarly, within the coffin of the Nordic nations, the study of Alola and Adebayo (2022) using the nonlinear strategy between 1990 and 2019 highlighted that increase (decrease) in renewable energy, energy intensity and eco-innovation decrease (increase) GHGs emissions. Contrarily, for the case of China, the studies of Akadiri et al. (2022) and Alola et al. (2022) documented the GHGs emissions increasing role of eco-innovation and green energy usage.

2.1. Contribution and research question

The analysis of ecological deterioration/quality in the literature has covered a variety of nations or nations from diverse geographic regions. While a few of these investigations have emphasized groups (e.g., MINT, G7 economies, NORDIC, BRICS, ASEAN, BRI, RECEP, WEMA, and MENA), others have looked at single-country instances (e.g., China, Japan, South Africa, USA, Russia, France, Nigeria and United Kingdom). Additionally, most research employed CO_2 emissions as a measure of environmental deterioration, however GHG emissions are a more comprehensive indicator of environmental degradation. From the standpoint of Iceland, a sparse investigation in the literature can be highlighted (e.g., Gricar et al., 2022; Su et al., 2023; Faisal et al., 2018). Nonetheless, majority of above-highlighted studies have examined the case of Iceland by using conventional econometric methods (e.g., ordinary least squares (OLS), dynamic OLS, vector autoregressive (VAR), fully modified OLS and ARDL), while others have conducted empirical research utilizing outdated data. Furthermore, most of the highlighted empirical literature have ignored the effect of fossil fuel, and metallic ores utilization on GHGs emissions. Furthermore, most studies deployed GHG emissions, CO_2 emission, and ecological footprint as environmental indicators, it is clearly uncommon to sample studies that disintegrate GHGs emissions into management, industrial and agriculture GHGs emissions. For this reason, it can be concluded that there is an existing and significant gap in the literature.

Considering the identified gap in the literature, this research concentrates on the Iceland scenario to more evidence on the drivers of environmental quality from the context of material consumption and sector wide GHG emissions. In this setting, the research examines the drivers of waste management, industrial and agriculture greenhouse gas emissions arising from domestic material consumption for biomass, domestic material consumption for fossil fuel and domestic material consumption for metal ores). As established by a survey of the literature, employing a novel Fourier ARDL alongside utilizing a more dated dataset provides significant addition to the literature. Therefore, it is reasoned that the investigation covers a significant gap in the literature. While using the case of Iceland which is sparsely reported in scientific literature, the following make up the basic research questions:

a. Does domestic material consumption for biomass contribute to ecological sustainability in Iceland?
b. What is the impact of domestic material consumption for fossil fuel on ecological sustainability in Iceland?
c. Does domestic material consumption for metal ores on ecological sustainability in Iceland?

3. Data and methods

This section presents the detailed description of the dataset and the empirical method. While the preliminary tests were conducted to direct the course of the empirical techniques, the main empirical technique is named and described.

3.1. Data

This paper concentrates on four distinct models to evaluate the connection between environmental proxies (Greenhouse gases, Industrial GHG, Agriculture GHG and Waste management GHG) and domestic material consumption biomass, domestic material consumption fossil fuel and domestic material consumption metal ores using yearly data stretching from 1990 to 2019 for the case of Iceland. After doing a comprehensive examination of the available literature, we discovered that none of the research utilized domestic material use of fossil fuel (nonrenewable) for the case of Iceland. In line with the study of (Awosusi et al., 2022) for the BRICS nations, the current study explores the role biomass on environmental degradation. Furthermore, we made improvement over the study of (Awosusi et al., 2022) by incorporating domestic material consumption biomass, domestic material consumption fossil fuel and domestic material consumption metal as drivers of the selected ecological proxies. The economic function of the models is highlighted below.

$$\mathrm{LnGHG_t} = \mathrm{f}(\mathrm{LnDMCB_t}, \mathrm{LnDMCF_t}, \mathrm{LnDMCMO_t}) \tag{1}$$

$$\mathrm{LnIGHG_t} = \mathrm{f}(\mathrm{LnDMCB_t}, \mathrm{LnDMCF_t}, \mathrm{LnDMCMO_t}) \tag{2}$$

$$\mathrm{LnAGHG_t} = \mathrm{f}(\mathrm{LnDMCB_t}, \mathrm{LnDMCF_t}, \mathrm{LnDMCMO_t}) \tag{3}$$

$$\mathrm{LnWGHG_t} = \mathrm{f}(\mathrm{LnDMCB_t}, \mathrm{LnDMCF_t}, \mathrm{LnDMCMO_t}) \tag{4}$$

where GHG, IGHG, AGHG and WGHG denotes Greenhouse gases, Industrial GHG, Agriculture GHG and Waste management GHG. Furthermore, DMCB, DMCF and DMCMO represents domestic material consumption biomass, domestic material consumption fossil fuel and domestic material consumption metal ores. In addition, the dependent variables which are GHG, IGHG, AGHG and WGHG are measured in Thousand tonnes while the independent variables which are DMCB, DMCF and DMCMO are measured in Tonnes and collected from Global Material Flows Database. Table 1 presents a precise data information.

To ensure normal distribution, the variables used in this paper are transformed into natural log as shown in Eq. (5):

$$\mathrm{LnY_t} = \pi_0 + \theta_1 \mathrm{LnDMCB_t} + \theta_2 \mathrm{LnDMCB_t} + \theta_3 \mathrm{LnDMCB_t} + \varepsilon_t \tag{5}$$

where Y represents the environmental proxies (GHG, IGHG, AGHG and WGHG), DMCB, DMCF and DMCMO signifies domestic material consumption biomass, domestic material consumption fossil fuel and domestic material consumption metal ores while ε_t signifies error term.

3.2. Theoretical framework

Energy is essential for the economic activities to take place. Moreover, energy is recognized as a crucial component of industry. Moreover, increasing energy usage especially from burning of fossil energy sources could undermine environmental quality while promoting economic growth (Ibrahim and Alola, 2020; Saint Akadiri et al., 2020). This assertion and related evidence are rooted in the early studies that associate environmental impacts with human activities especially from the perspective of affluence, population dynamics, and growth (Dietz and Rosa, 1994; York et al., 2003).

Clearly, as reported by the United Nations Development Programme (UNDP), countries may significantly advance sustainable development drive through a more efficient and modern approach to biomass energy utilization (UNDP, 2015). The use of biomass energy is a crucial component of efforts to attain sustainability in debates of climate change policies and

Table 1
Data source, measurement, and variables.

Symbol	Variables	Measurement	Source
DMCB	Domestic Material Consumption for Biomass	Tonnes	Global Material Flows Database
DMCF	Domestic Material Consumption for Fossil Fuel	Tonnes	Global Material Flows Database
DMCMO	Domestic Material Consumption for Metal Ores	Tonnes	Global Material Flows Database
GHG	Greenhouse gases	Thousand tonnes	World development indicator
IGHG	Industrial GHG	Thousand tonnes	Eurostat
AGHG	Agriculture GHG	Thousand tonnes	Eurostat
WGHG	Waste management GHG	Thousand tonnes	Eurostat

strategies that are viewed as necessary for sustainable growth (Umar et al., 2021). Because it is one of the main sources that may be used to cut emissions, biomass energy is significant. Moreover, it is anticipated that using biomass energy will have a negative impact on carbon emissions by decreasing ecological degradation since it allows for more advanced and contemporary ways of producing and using energy. The globe might effectively improve and support economic growth while simultaneously reinforcing its ecological standards by altering the way energy is produced and used. In this framework, increases in the accessibility of biomass resources would offer a stable framework for a sustainable energy infrastructure that encourages a sustainable way of life. Because it is clean and abundant, biomass energy is one of the most important sources of renewables that offers effective substitute for the use of fossil fuels, and especially accounting for almost 60 % of EU's renewable energy sources (European Commission, 2019).

Moreover, greenhouse gas (GHG) emissions from the production of metals also make up a sizeable portion of overall emissions (United States Environmental Protection Agency, 2022). Metals are important to human existence, and as the world's population and economy expand, so will demand for them. Based on research by the International Resource Panel, the production of metals is responsible for around 10 % of the world's greenhouse gas emissions (IRP, 2019). Several aspects of the metal cycle, industrial technology, and energy transition, such as metal consumption level, recycling rate, product lifespan, and emission intensities, have an impact on the rise of the metal demand and related environmental implications. As a result, it is projected that metal use would raise GHG emissions and thus reduce ecological quality.

3.3. Methods

Structure breaks are ignored in conventional residual-based cointegration investigations. Numerous cointegration tests, such as Gregory and Hansen (1996) and Hatemi-J (2008) accommodate severe structural break(s) to prevent this omission. Dummy variables are employed to identify structural break(s) in the cointegration tests produced in this manner, and they only permit for time-specific and abrupt alterations. It is feasible to consider numerous smooth structural shifts with undefined time, number, and form by applying Fourier functions. By including the trigonometric components into McNown et al. (2018)'s suggested bootstrap ARDL approach, the researchers created the Fourier ARDL method. In essence, these techniques are developed from the conventional ARDL technique. Eq. (6) represents the conventional ARDL method.

$$\begin{aligned}\Delta \mathrm{InY_t} = {} & \pi_0 + \theta_1 \sum_{i=1}^{u} \Delta \mathrm{InY_{t-i}} + \theta_2 \sum_{i=0}^{k} \Delta \mathrm{InDMCB_{t-i}} \\ & + \theta_3 \sum_{i=0}^{p} \Delta \mathrm{InDMCF_{t-i}} + \theta_4 \sum_{i=0}^{d} \Delta \mathrm{InDMCMO_{t-i}} + \varphi_1 \mathrm{InY_{t-1}} \\ & + \varphi_2 \mathrm{InDMCB_{t-1}} + \varphi_3 \mathrm{InDMCF_{t-1}} + \varphi_4 \mathrm{InDMCMO_{t-1}} + \varepsilon_t \end{aligned} \tag{6}$$

where Y denotes the proxies of environmental degradation i.e., GHG, IGHG, AGHG and WGHG. Also, $\theta_{1,2,3\ and\ 4}$ and $\varphi_{1,2,3\ and\ 4}$ denotes short and long-run coefficients respectively while ε_t depicts the error term. The dependent variable must be I(1) for the two tests, $\mathrm{t_{dependent}}$ and $\mathrm{F_{overall}}$, used in the ARDL bounds test technique to assess the cointegration connection. The independent and dependent variables coefficients are subjected to the F- and *t*-tests. When the null hypotheses in Eq. (7) are disproved for both tests, cointegration is proven to exist.

$$F_{overall}H_0 : \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = 0; t_{dependent}H_0 : \varphi_1 = 0 \tag{7}$$

Nevertheless, most scholars simply utilize the overall test. In this scenario, degenerate situations arise if the coefficient of the dependent variable is equal to "zero," which means that there is no cointegration. The limited size and power characteristics of some unit root tests also prevent some researchers from conclusively determining whether the dependent variable is stationary or not in the first difference. To circumvent these issues, (McNown et al., 2018) suggest a new test ($\mathrm{F_{independent}}$) that is exclusively used to the independent variables. This test also does away with the need that the dependent variable be I(1). Eq. (8) illustrates the $\mathrm{F_{independent}}$ test's null hypothesis, which is the absence of cointegration.

$$\mathrm{F_{overall}H_0} : \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = 0 \tag{8}$$

In the bootstrap ARDL technique suggested by McNown et al. (2018), all three test statistics in Eqs. (6) and (7) must be significant statistically for cointegration to exist. When one of the tests does not satisfy this criterion, no-cointegration is indicated, and degenerate situations arise. The following present the degenerate scenarios:

- Degenerate case 1 arises if the t-dependent is not significant statistically but the other two statistics are.
- Degenerate case 2 arises if the $\mathrm{F_{independent}}$ is not significant statistically but the other two statistics are.

The conventional ARDL technique's unstable assumption of cointegration is also eliminated since the bootstrap ARDL method creates critical values utilizing bootstrap simulation. This is due to a data generation process in the conventional ARDL technique that relies on whether all regressors are I(0) or I(1), and a test statistic between these critical values, referred to as the upper and lower limits, correspondingly, does not give exact cointegration information. Because they offer a clear and single critical value, bootstrap simulations aid in eliminating this uncertainty. Though the bootstrap ARDL technique disregards smooth breaks, sharp breaks can be incorporated in the analysis with the dummy variable. The bootstrap ARDL is extended in recent studies by incorporating Fourier terms (Solarin, 2019; Pata and Aydin, 2020). It is desirable in the use of the Fourier ARDL approach to avoid looking for the I(1) condition regardless of the dependent variable. In Eq. (9), the ARDL model is stated using Fourier terms.

$$\begin{aligned}\Delta \mathrm{InY_t} = {} & \pi_0 + \theta_1 \sum_{i=1}^{u} \Delta \mathrm{InY_{t-i}} + \theta_2 \sum_{i=0}^{k} \Delta \mathrm{InDMCB_{t-i}} \\ & + \theta_3 \sum_{i=0}^{p} \Delta \mathrm{InDMCF_{t-i}} + \theta_4 \sum_{i=0}^{d} \Delta \mathrm{InDMCMO_{t-i}} + \varphi_1 \mathrm{InY_{t-1}} \\ & + \varphi_2 \mathrm{InDMCB_{t-1}} + \varphi_3 \mathrm{InDMCF_{t-1}} + \varphi_4 \mathrm{InDMCMO_{t-1}} + \vartheta_5 \sin \\ & + \left(\frac{2k\pi t}{T}\right) + \vartheta_6 \mathrm{Cos} + \left(\frac{2k\pi t}{T}\right) + \varepsilon_t \end{aligned} \tag{9}$$

The fractional optimal frequency is denoted by k, period is represented by T, t signifies trend term, and =3.1416 are all defined in Eq. (9). k is utilized to identify structural break(s). For the occurrence of cointegration in the Fourier ARDL technique, all three tests in the bootstrap ARDL must be significant statistically.

The research's econometric structure is divided into four empirically-defined phases (see Fig. 1). The Fourier-ADF unit root test is used in the initial step to examine the stochastic characteristics of the series. In the second step, Fourier terms are used to examine the possibility of cointegration. The coefficients are calculated using the Fourier ARDL technique in the third step. In the fourth step, Fourier Toda Yamamoto causality analysis is used to investigate the causal relationship between the variables.

4. Results and discussion

4.1. Preliminary test results

The present study commenced by presenting brief statistical information regarding the basic tests prior to the main estimation. Table 2 presents the brief information on the variables of study. The mean of LnDMCB (14.430) is the highest which ranges from 14.115 to 14.701. This is accompanied by LnDMCMO (12.635) which ranges from 10.940 to 13.727, LnDMCF (12.038) which ranges from 11.385 to 12.476, LnGHG (9.507)

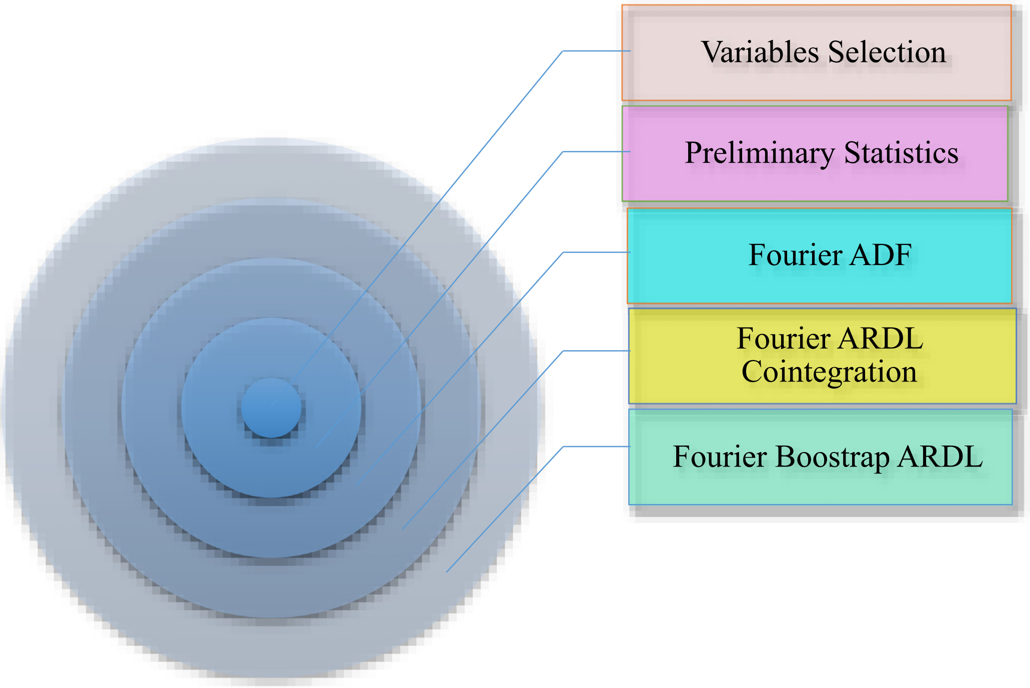

Fig. 1. Flow of the study.

which ranges from 9.439 to 9.591, LnIGHG (7.075) which ranges from 5.391 to 7.643, LnAGHG (6.449) which ranges from 6.396 to 6.498 and LnWGHG (5.624) which ranges from 5.391 to 5.804. The skewness value shows that with the exemption of LnDMCB, all the series are skewed negatively while the results of the kurtosis uncovered that the series are platykurtic in nature since their values are less than 3. Moreover, Fig. 2 presents additional basic information regarding the variables of investigation.

Table 3 displays the results of the BDS test for each pair of variables. We can easily see that across all embedding (m) dimensions, the null of a linear dependence can be rejected. Each series' non-linearity is verified by the BDS test. This bolsters the idea that the indicators are connected by a nonlinear relationship. Because of this, we can statistically demonstrate that utilizing a linear approach in this inquiry would provide unreliable results.

4.2. Fourier ADF and conventional ADF results

Finding the integration levels of the indicators for the Fourier autoregressive distributed lag (FARDL) cointegration test is the first step in the primary analysis (see Table 4). The dependent variable must be I(1) under a certain precondition, however the regressors may be I(0)/I(1). As a result, two tests—the FADF test and the ADF test are employed. The latter is proposed by (Enders and Lee, 2012) and incorporates a Fourier function to the ADF unit root test regression to enable numerous smooth structural modifications. The LnDMCB and LnDMCF F-statistics generated in this study's FADF unit root test was determined to be less than the critical levels. Consequently, for these indicators, the traditional ADF unit root test was utilized. In contrast, F-statistics for LnDMCMO, LnGHG, LnIGHG, LnWGHG, and LnAGHG are significant. Thus, as indicated in Table 4, the FADF unit root test is employed such that with the exception of LnDMCMO, all series are I(1).

4.3. Fourier cointegration results

Secondly, the long-run interrelationship between indicators by utilizing the Fourier bootstrap ARDL cointegration test are evaluated. Table 5 uncovers the cointegration outcomes for the models utilized in the research. Based on these results, there is evidence of interrelationship between indicators in the long run. In other words, LnDMCB, LnDMCF and LnDMCMO and the ecological proxies (LnGHG, LnIGHG, LnWGHG and LnAGHG) move together in the long-run. After affirming the cointegration, the FARDL is then deployed for the coefficient estimation.

4.4. Fourier ARDL results

To evaluate the long and short-run nexus between ecological proxies (LnGHG, LnIGHG, LnWGHG and LnAGHG) and the regressors, the current research employed the novel FARDL. The short-run and long-run results are comparable. As indicated in Table 6, the coefficient of ECT in each model is negative and statistically significant which is as expected. These findings suggest that short-run instability can be rectified to long-run equilibrium, resulting in a long-term connection between the indicators involved.

The result obtained from FARDL (see Table 6) shows negative nexus between domestic material consumption biomass and ecological proxies

Table 2
Descriptive statistics.

	LnGHG	LnDMCB	LnDMCF	LnDMCMO	LnIGHG	LnWGHG	LnAGHG
Mean	9.507	14.430	12.038	12.635	7.075	5.624	6.449
Median	9.500	14.447	12.149	12.542	6.915	5.638	6.447
Maximum	9.591	14.701	12.476	13.727	7.643	5.804	6.498
Minimum	9.439	14.115	11.385	10.940	6.275	5.391	6.396
Std. Dev.	0.044	0.184	0.334	0.930	0.487	0.118	0.027
Skewness	−0.093	0.009	−0.516	−0.413	−0.253	−0.283	−0.096
Kurtosis	1.815	1.765	1.884	1.821	1.623	2.068	2.442

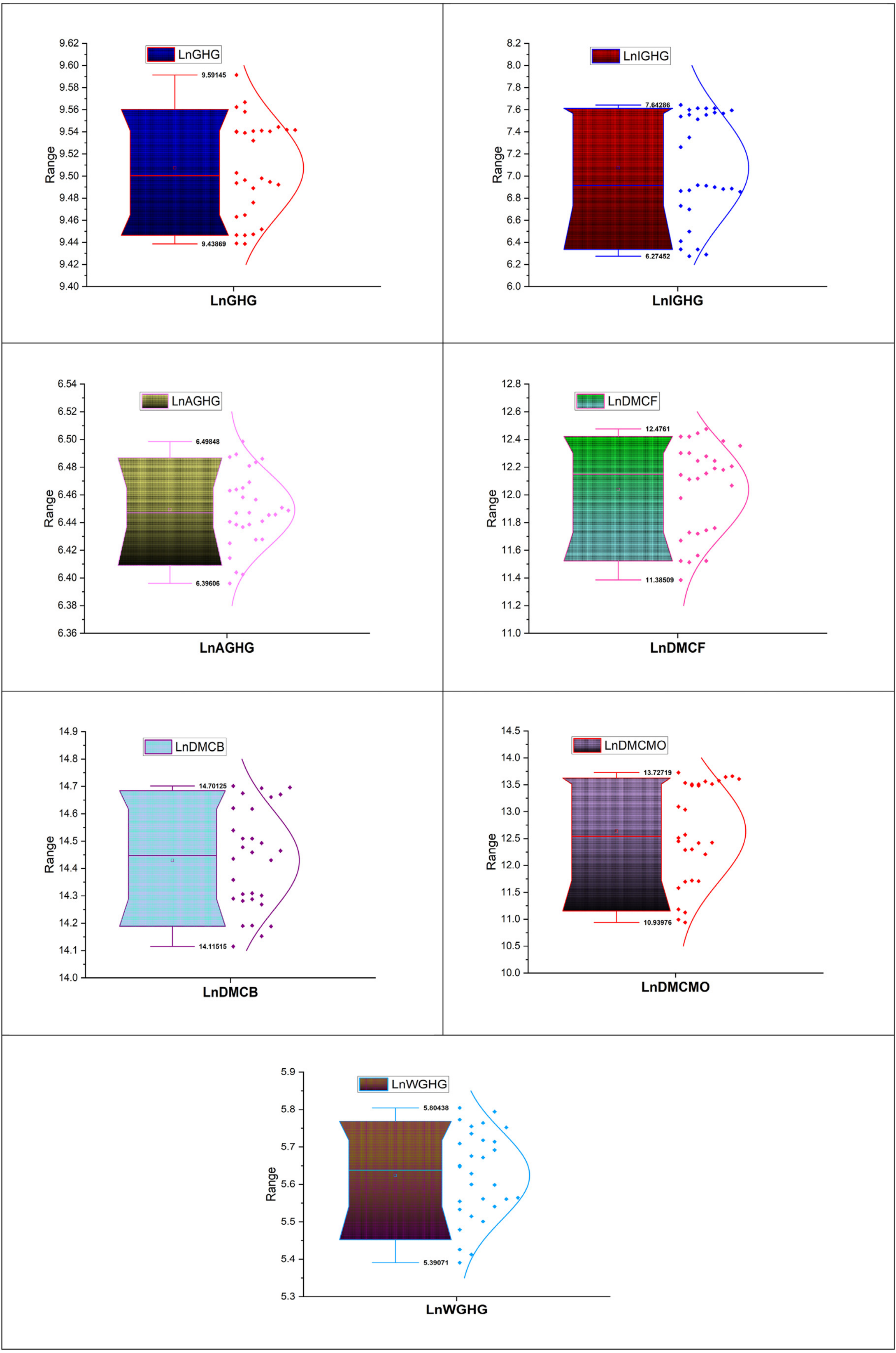

Fig. 2. Box plot.

Table 3
BDS test.

	LnGHG	LnDMCB	LnDMCF	LnDMCMO	LnIGHG	LnWGHG	LnAGHG
M2	0.202*	0.104*	0.116*	0.130*	0.148*	0.182*	0.098*
M3	0.343*	0.147*	0.182*	0.210*	0.221*	0.312*	0.140*
M4	0.442*	0.163*	0.215*	0.285*	0.236*	0.397*	0.155*
M5	0.515*	0.152*	0.184*	0.301*	0.288*	0.448*	0.144*
M6	0.567*	0.133*	0.113*	0.328*	0.316*	0.484*	0.125*

Note: m signifies the amount of (embedded) dimensions.
* Signifies 1 %.

(LnGHG, LnIGHG, LnWGHG and LnAGHG). In specific, 1 % upsurge in domestic material consumption biomass decrease LnGHG by LnIGHG, LnWGHG and LnAGHG in the short and long-term. The results reinforced the emissions decreasing effect of domestic material consumption biomass in Iceland. According to these findings, biomass enhances ecological integrity in Iceland, which lowers GHG emissions. The fact that Iceland' use of biomass energy results in a smaller GHGs emissions confirms the value of biomass as a weapon for halting ecological destruction, which enables the achievement of the SDGs 13 objective. The finding confirms our assumption and numerous other research, including (Korkut Pata et al., 2022; Shahbaz et al., 2019; Xin et al., 2022), which shows how biomass-based renewable energy can help prevent ecological damage. Additionally, this result is consistent with study conducted in the BRICS nations by Awosusi et al. (2022) which found that using biomass energy minimizes environmental degradation. This analysis also lends support to the recent argument put out at COP27 emphasizing the necessity of removing the barriers preventing the spread of renewable energy. The study of Xin et al. (2022) highlight that as a result of recent technological growth, the growth of biomass energy has been linked to large decreases in ecological deterioration.

Table 4
Fourier ADF and ADF tests results.

Variable	Fourier-ADF Test					ADF		P
	I(0)	I(1)	k(0)/k(1)	p(0)/p(1)	F-Stat.	I(0)	I(1)	I(0)I(1)
LnDMCB	0.672	–	3	1	2.780	0.864	−4.907*	0/0
LnDMCF	1.038	–	1	2	3.038	−0.874	−5.096*	0/0
LnDMCMO	−4.693*	–	1	1	14.846*	–	–	–
LnGHG	−1.738	−4.639*	1	3	0.480	–	–	–
LnIGHG	−1.482	−4.571*	1	1	15.502*	–	–	–
LnWGHG	−1.653	−4.749*	5/5	2/2	13.948*	–	–	–
LnAGHG	−1.708	−5.438*	4/4	3/3	13.948*	–	–	–

Notes: the dismissal of the null hypothesis at 1 % significance level is shown by *. p and k show the optimal lag length and frequency number of Fourier terms.

Table 5
Fourier ARDL cointegration analysis.

	Model	AIC	k	f-stat	t-dep	f-indep
LnGHG = f(LnDMCB, LnDMCF, LnDMCMO)	FARDL (1,1,1,0)	−4.859	2.00	8.058**	−4.959**	9.649*
		1 %		9.093	−5.382	8.947
		5 %		7.469	−4.893	7.452
LnIGHG = f(LnDMCB, LnDMCF, LnDMCMO)	FARDL (1,2,1,1)	−4.403	2.40	7.480*	−4.795*	8.048*
		1 %		6.648	−5.430	6.995
		5 %		5.359	−4.430	5.823
LnAGHG = f(LnDMCB, LnDMCF, LnDMCMO)	FARDL (2,1,0,2)	−4.694	1.56	4.123**	−3.939*	5.424*
		1 %		3.701	−2.826	2.988
		5 %		4.539	−3.404	3.720
LnWGHG = f(LnDMCB, LnDMCF, LnDMCMO)	FARDL (2,1,1,1)	−4.475	2.60	5.802**	−4.905*	6.274*
		1 %		5.103	−4.735	5.537
		5 %		4.228	−3.641	4.593

Note: 1 % and 5 % levels are denoted by * and **, respectively. 1000 bootstrap replications have been used.

Table 6
Fourier ARDL results.

	LnGHG		LnIGHG		LnAGHG		LnWGHG	
	Coefficient	*P*-value	Coefficient	*P*-value	Coefficient	*P*-value	Coefficient	*P*-value
Long-run results								
LnDMCB	−0.039***	0.066	−0.053	0.580	−0.040*	0.010	−0.025***	0.076
LnDMCF	−0.062*	0.004	−0.180***	0.077	−0.002	0.889	0.155	0.108
LnDMCMO	0.019**	0.014	0.237*	0.000	0.005	0.559	−0.005	0.824
SIN	0.005	0.175	0.009	0.594	0.013**	0.017	0.003	0.734
COS	0.009**	0.043	0.064*	0.006	0.033*	0.000	0.031**	0.028
C	5.994	0.008	1.937	0.584	1.292	0.000	2.618	0.009
Short-run results								
ΔLnDMCB	−0.132***	0.056	−0.193***	0.054	0.099*	0.000	−0.155*	0.000
ΔLnDMCF	−0.009	0.360	−0.237	0.135	0.091*	0.001	−0.086***	0.082
ΔLnDMCF$_{t-1}$	–	–	0.193	0.739	–	–	–	–
ΔLnDMCMO	0.019*	0.001	−0.252**	0.034	−0.002	0.833	0.003	0.692
ΔLnDMCMO$_{t-1}$	–	–	–	–	0.005	0.103	–	–
ΔSIN	0.011***	0.062	0.009**	0.014	0.013*	0.007	0.031*	0.008
ΔCOS	0.005***	0.097	0.064**	0.016	0.033*	0.000	0.039	0.374
C	0.009**	0.021	1.937*	0.000	1.186*	0.000	1.618*	0.000
ECT (−1)	−0.428*	0.000	−0.158*	0.000	−0.721	0.000	−0.266	0.000

Note: Significance level of 1 %, 5 % and 10 % is depicted by *, ** and ***. Δ depicts short term.

Table 7
Nexus of sectoral GHG emissions and DMC components in Iceland.

Interpretation		GHG	IGHG	AGHG	WGHG
DMCB	*Short run*	Mitigation	Mitigation	Stimulation	Mitigation
	Long run	Mitigation	No effect	Mitigation	Mitigation
DMCF	*Short run*	No effect	No effect	Stimulation	Mitigation
	Long run	Mitigation	Mitigation	No effect	No effect
DMCMO	*Short run*	Stimulation	Mitigation	No effect	No effect
	Long run	Stimulation	Stimulation	No effect	No effect

Table 8
Post estimation tests results.

	LnGHG		LnIGHG		LnAGHG		LnWGHG	
	Test stat.	*P*-value	Test stat.	*P*-value	Test stat.	*P*-value	Test stat.	*P*-value
JB	1.052	0.590	0.712	0.700	0.955	0.620	0.106	0.948
RESET	0.660	0.527	0.496	0.625	1.227	0.239	0.660	0.527
LM	1.245	0.344	0.994	0.389	1.599	0.239	1.860	1.898
BGP	0.568	0.848	0.994	0.389	0.832	0.613	1.983	0.101

Surprisingly, the study uncovers a negative connection between domestic material consumption fossil fuel and ecological proxies (LnGHG, LnIGHG, and LnAGHG). This implies that holding other factors constant, a 1 % upsurge in domestic material consumption fossil fuel decrease LnGHG by LnIGHG, and LnAGHG in the short and long-term. The results reinforced the emissions decreasing effect of domestic material consumption fossil fuel in Iceland. Thus, domestic material consumption fossil fuel improved ecological quality in Iceland. This result regarding this connection is as expected given Iceland swift and sustainable transition towards renewable energy Unlike other Nordic countries such as Sweden (25.12 %), Finland (40.21 %), Norway (56.95 %), Denmark (64.93 %) and Norway (56.95 %), Iceland fossil fuel consumption in 2015 was roughly 11.29 %[1]. In addition, locally produced renewable energy sources provide for 85 % of Iceland's entire primary energy supply. In any country's energy budget, Iceland proportion of renewable energy is the largest. This information's shows the low dependence of Iceland on Fossil fuel energy and as result, meeting the SDGs can be achieved easily. Iceland offers a distinctive case in a time when nations all over the world are required to deploy sustainable energy solutions due to climate change. For clarity, Table 7 presents the summary of the nexus of sectoral GHG emissions and DMC components in Iceland.

Nearly all the power utilized in Iceland is produced from renewable energy.[2] Additionally, geothermal energy is used to directly heat nine out of ten homes. Other nations looking to enhance their use of renewable energy might draw inspiration from Iceland's experience in making the switch away from fossil fuels. The result obtained contradicts the conventional results presented by prior studies. For instance, the study of Adebayo (2022) in Spain using the novel wavelet reported that in all frequencies, fossil fuel energy drives ecological deterioration positively. Likewise, the studies of Abbasi et al. (2022), Adebayo (2022), and Tsai et al. (2016) documented positive nexus between fossil fuel and ecological deterioration.

Lastly, the study unveils a positive connection between domestic material consumption metal and ecological proxies (LnGHG, LnIGHG, and LnAGHG). This implies that holding other factors constant, a 1 % upsurge in domestic material consumption metal ore increase LnGHG by LnIGHG, and LnAGHG in the short and long-term. The results reinforced the emissions increasing effect of domestic material consumption metal ore in Iceland. This result is as expected given the fact that the greenhouse gas (GHG) emissions from the production of metals also make up a sizeable portion of overall emissions. Metals are important to human existence, and as the world's population and economy expand, so will demand for them. The study of Li et al. (2018) affirm the current result.

Summarily, the results discussed above are carefully highlighted in Table 7. Specifically, the short- and long-run GHG emission impacts of DMCB, DMCF, and DMCMO across the industrial, agricultural, waste management, and aggregated sector are summarily tabulated for clarity.

4.5. Post estimation results

These Fourier ARDL technique results, as depicted in Table 8, are free of issues like heteroskedasticity, autocorrelation, non-normality, and unstable coefficients. The findings of the BGP, LM, and JB tests reveal that there is no heteroscedasticity issue, and that the error terms are distributed normally. The LM test also demonstrates that the error terms do not include issues of autocorrelation. Furthermore, the CUSUM and CUSUM of sq. also affirm the stability of the models (see Figs. 3, 4, 5 and 6).

5. Conclusion and policy recommendation

Following the EU's ESR which encourages emission reduction measures across the economic sectors, Iceland is keeping up with the directive along the country's nationally determined contribution (NDC). Given its NDC measure, Iceland's renewed CAP 2020 targets a significant reduction in GHG emission across five major sectors (energy production and small industry, waste management, ships and ports, land transport, and agriculture). With this EU's commitment, and drawing from the case of Iceland, this investigation was a direct attempt at examining how GHG emissions in aggregate and across the industrial, agriculture, and waste management sectors have varied over the duration 1990–2019 with respect to domestic material consumptions of biomass, fossil fuels, and metallic ores. By doing so, the Fourier functions for stationarity, cointegration and long-run coefficient estimations were employed. Having satisfied the pre-conditions, the Fourier ARDL analysis posits that biomass and fossil fuels domestic material consumptions have caused statistically significant reduction in aggregate GHG emissions especially in the long run, but metallic ores domestic material consumptions over the same period have further contributed to GHG emissions. Meanwhile, across the sectors (industrial, agriculture, and waste management), the result is quite varying. For instance, biomass DMC mitigates GHG emissions in waste management in the short- and long run, mitigate industrial GHG emission in short run with no effect in the long run, and stimulate agricultural GHG emission in the short run but reducing the emission in the long run.

To further guide Iceland's determination to secure about 40 % reduction in GHG emission across the main sectors specified in the EU's ESR by 2050 and achieving the country's carbon neutrality by 2040, the following policy insight derived from the result of the investigation could be helpful. Activities in the industrial sector which include the service (transportation) and production activities could be further incentivized through fiscal and financial instruments especially for the motive of driving sustainable development and environmental sustainability. For instance, more credit facilities, subsidies, and increase in investment portfolios especially that could encourage rapid energy transition and clean energy utilization should improve green industrial activities. Additionally, with green investment through increasing research and development and credit availability for green entrepreneurial activities, this will not only expand green economy

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[1] https://www.macrotrends.net/countries/ISL/iceland/fossil-fuel-consumption.

[2] https://www.government.is/topics/business-and-industry/energy/.

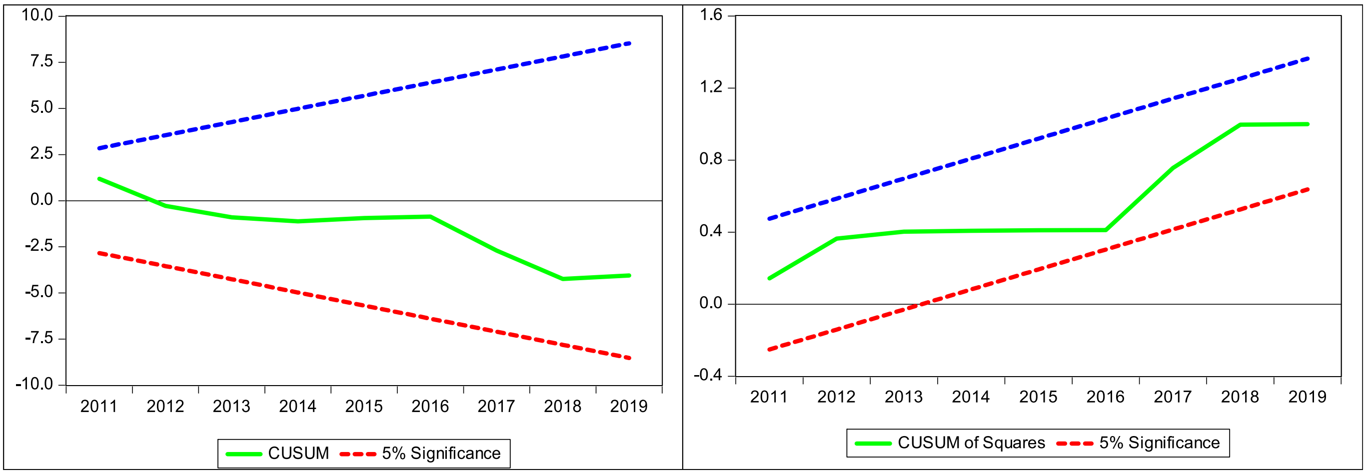

Fig. 3. GHG model stability result.

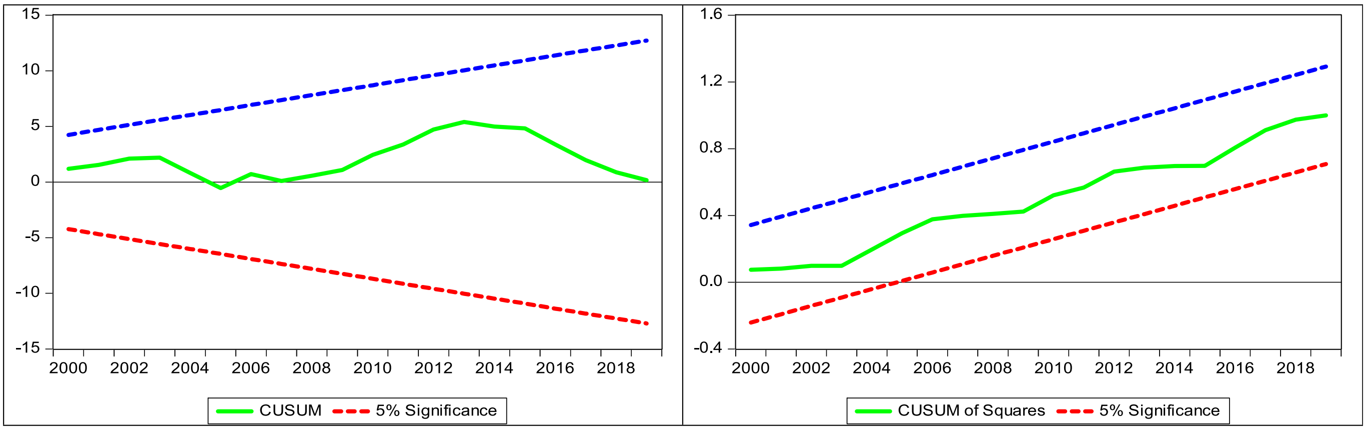

Fig. 4. LnIGHG model stability result.

but promotes sector wide productivity with minimal environmental drawback. Furthermore, policy guideline for consumption and production of materials for both domestic use and exportation purposes should further be critiqued for specificity i.e., based on biomass, fossil fuel, and metallic ores components. Importantly, this could further help in refining and adopting more appropriate material or resource circularity concept especially as per biomass, fossil fuels, and metallic ores. Moreover, employing this approach should translate to the replication of the expected success in other economic and socioeconomic activities such as agriculture and complimenting the seemingly achievement in waste

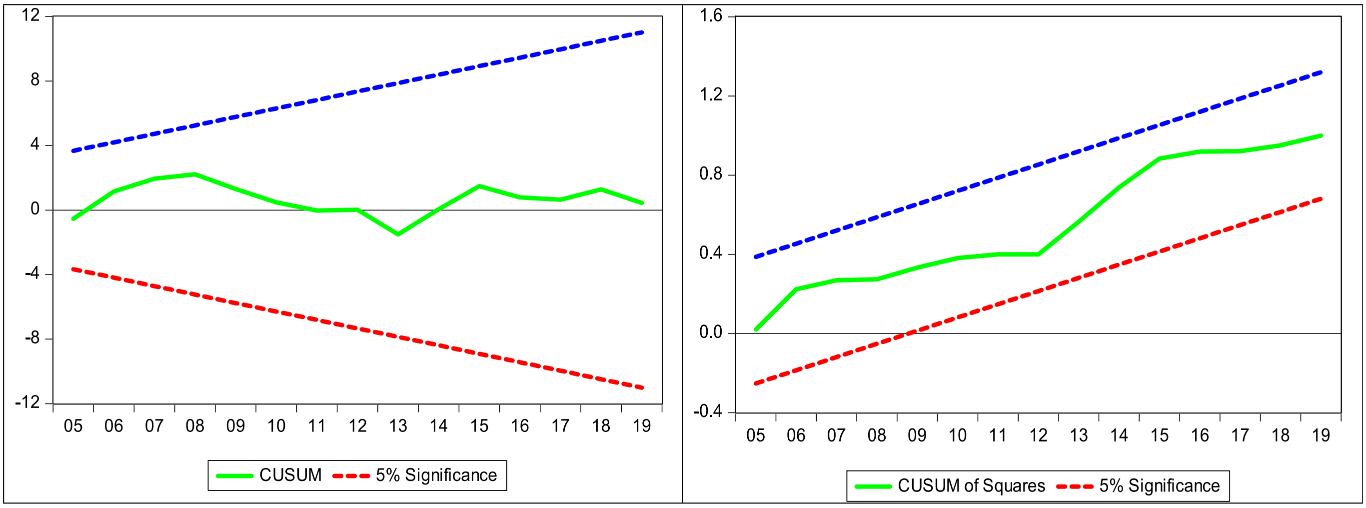

Fig. 5. LnAGHG model stability result.

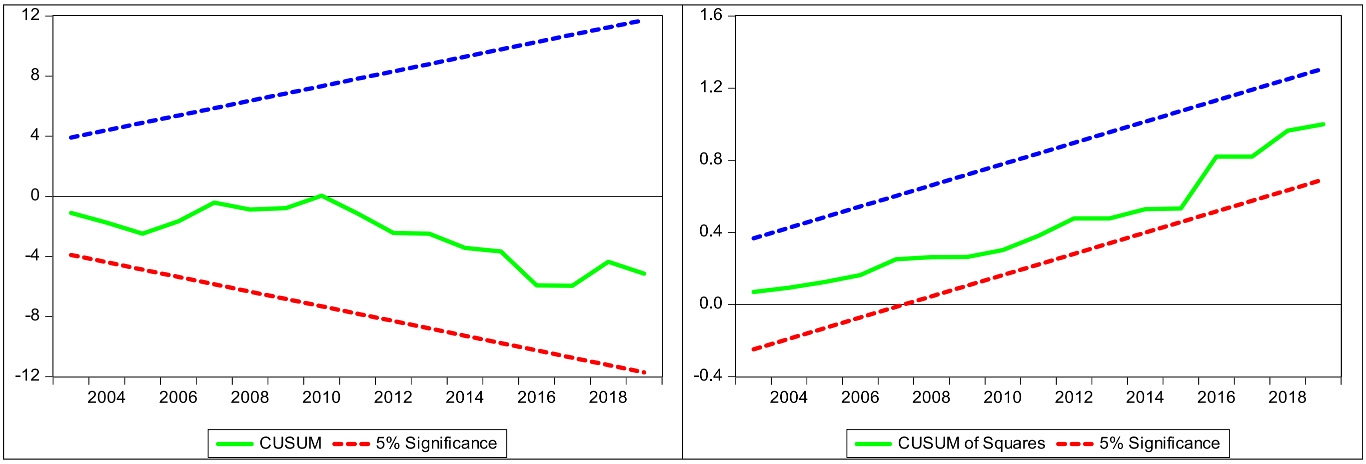

Fig. 6. LnWGHG model stability result.

management activities. Generally, the above-mentioned specific measures are clearly encapsulated in the European Green Deal policy of the EU, thus making these policy-specific recommendations applicable to the EU member states.

Given the significant attempt to arrive at the objective of this investigation and expand the literature on environmental impacts, yet the outcome of the investigation presents some limitations that could be reconsidered in future study. To begin, this research solely looks at Iceland. As a result, future research may consider other developed and developing nations, as well as different countries bloc. Secondly, this research is based on restricted numbers of selected dependent and explanatory variables. As a result, further research can consider other aspects that were not included in this research, especially the socioeconomic factors such as country-specific demographics, political risk, economic policy uncertainty, and globalization. Fourth, this research considers aggregated (macro) country level analysis, thus future study can disaggregate the sector activities to the micro-levels to critically pinpoint and match the activities with the sets of appropriate emission reduction policies. Finally, the research employs a unique Fourier technique to examine the period between 1991 and 2019. However, prospective research might accommodate later or updates dataset such that additional unique approaches like quantile approach, wavelet tools and Rowling window approach are deployed in future experimentation.

CRediT authorship contribution statement

Tomiwa Sunday Adebayo: Methodology; Conceptualization; Formal analysis.

Andrew Adewale ALOLA: Data; Writing - original draft; Investigation; Supervision, and Corresponding.

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Data availability

Data will be made available on request.

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.

Appendix A

Abbreviations
AGHG: Agriculture greenhouse gas emissions
ARDL: Autoregressive distributed lag
CAP: Climate Action Plan
CCR: Canonical correlation regression
CO_2: Carbon Emissions
DMC: Domestic material consumption
DMCB: Domestic material consumption for biomass
DMCF: Domestic material consumption for fossil fuel
DMCMO: Domestic material consumption for metal ores
ESR: Effort sharing regulation
EU: European Union
FARDL: Fourier autoregressive distributed lag
GDP: Gross domestic product
GHG: Greenhouse gases
IGHG: Industrial greenhouse emissions
LMDI: Logarithmic Mean Divisia Index
OECD: Organisation for Economic Co-operation and Development
OLS: Ordinary least squares
PMG: Pooled mean group
VAR: Vector autoregressive
WGHG: Waste management greenhouse emissions

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