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Research article

The environmental aspects of renewable energy consumption and structural change in Sweden: A new perspective from wavelet-based granger causality approach

Tomiwa Sunday Adebayo [a], Ridwan Lanre Ibrahim [b], Ephraim Bonah Agyekum [c], Hossam M. Zawbaa [d,e,*], Salah Kamel [f]

[a] *Department of Economics, Faculty of Economics and Administrative Science, Cyprus International University, Nicosia, Northern Cyprus, TR-10 Mersin, Turkey*
[b] *Department of Economics, University of Lagos, Akoka, Lagos State, Nigeria*
[c] *Ural Federal University Named After the First President of Russia Boris Yeltsin, 19 Mira Street, Ekaterinburg, 620002, Russia*
[d] *Faculty of Computers and Artificial Intelligence, Beni-Suef University, Beni-Suef, Egypt*
[e] *Technological University Dublin, Dublin, Ireland*
[f] *Department of Electrical Engineering, Faculty of Engineering, Aswan University, Aswan, 81542, Egypt*

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ABSTRACT

The current paper assessed the time-frequency analysis interrelationship between CO_2 emissions and financial development, economic growth, renewable energy use, structural change, and non-renewable energy use in Sweden. We utilized a quarterly dataset stretching from 1980-2019. In order to unlock these interrelationships, we leverage wavelet tools (wavelet-based Granger causality and wavelet coherence). The wavelet-based Granger causality (WGC) test accounts for the issue of multiple time scales in a time series analysis. Another uniqueness of the WGC lies in its resistance to distribution assumption and misspecification in a time series model. Additionally, the wavelet coherence estimator instantaneously evaluates correlation and causality among the interacting indicators in a model. The outcomes of the wavelet coherence exposed that renewable energy, financial development, economic growth, structural change, and trade openness enhance the environment's quality while non-renewable energy intensifies CO_2. Moreover, the WGC shows that all the variables can predict each other. Based on these findings, policymakers in Sweden should focus more on improving public understanding of renewable energy and environmental preservation. We believe that Sweden's shift to service-sector-led growth will help to safeguard the environment.

1. Introduction

The menace of global warming remains one of the topmost challenging issues of the present era. Among many other reasons, the surging greenhouse gas (GHG) emissions which refused to drop significantly despite relentless efforts, remain a cause of concern for policymakers, intergovernmental organizations, and research pundits alike (Kahn et al., 2021; Lamb et al., 2021). The ensuing effects of this unresolved environmental problem are evident in the demeaning environmental quality and drastically diminishing longevity (Khan et al., 2022b; Rjoub et al., 2021). To this end, nations work assiduously to keep global warming below 2 °C and achieve a limit within 1.5 °C (Bekun, 2022; Oke et al., 2021; Provost, 2019). The emerging actions on climate change have witnessed unprecedented success on globally adopted action plans and agreements towards achieving a sustainable environment characterized by net-zero emissions by 2050. On the international level, the United Nations 26th Conference of the Parties (COP26), which covers above 90% of global gross domestic products and carbon emissions net-zero pledge, sets new directions for nations to pursue. Additionally, the United Nations 2030 sustainable development goals (SDGs) entail another set of ambitious goals and commitments to significantly reduce GHG emissions and provide a viable platform for achieving sustainable development's economic, social, and environmental dimensions. Within the framework of these global initiatives, countries at the national level are not left out of the struggle. The reason is that without countries fulfilling their Nationally Determined Commitments (NDCs) pledges on carbon emissions reduction, achieving the global target will remain an illusion. Among several countries that have shown significant

* Corresponding author.
E-mail address: hossam.zawbaa@gmail.com (H.M. Zawbaa).

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commitments to substantially halt the pervasive surge in carbon emissions for environmental sustainability, the Swedish economy standouts for at least four reasons (Erdoğan et al., 2022; Joshua et al., 2022; Mujtaba et al., 2022).

First, Sweden is an epitome of an economy setting the pace for a sustainable environment through commitments and pragmatic policies to achieve net-zero emissions by 2050. The country constitutes the first economy to enact and implement the environmental protection act, which came into being in 1967 (Khan et al., 2022a). Besides, it was the first to host the United Nations conference that deliberated and marshaled the pathway on global environmental sustainability in 1972 (Santosh, 2021). Since the emergence of the global commitment in 1972, Sweden has remained persistent in cleaning up its atmosphere from the effects of anthropogenic emissions. Given this, the country maintains a balanced cause between minimizing the volume of carbon emissions and significantly growing its economy, making it one of the most sustainable economies globally. Second, there is a massive evolution from fossil fuels to renewables in Sweden (Shan and Lü, 2021). This action plan for the transition is well articulated in the country's 2050 roadmap of becoming the first to achieve a fossil-fuel-free economy (Ma et al., 2021; Zhong et al., 2021). This transitional plan has resulted in a 40% reduction in GHG emissions between 1990 and 2020 (Martinsson and Hansson, 2021; Salvia et al., 2021). The significant reduction in GHG emissions is due to the country's generation of 80% of electricity from nuclear and hydroelectric power. The country presently operates three nuclear facilities and eight reactors for commercial purposes. As of 2020, 50% of the national renewable energy utilization was achieved with plans to reach 100% electricity generation switch to renewable energy (Brodny et al., 2021; Ma et al., 2021).

Third, carbon tax and pricing, which became acceptable strategies that many countries are adopting to mitigate carbon emissions, emanated from Sweden (Andersson, 2019). These policies have seen Sweden become the most expensive economy in terms of carbon prices placed on carbon-intensive fuels comprising natural gas and fuel (Green, 2021). Available statistics uncover that as of 2012, revenues generated through environmental tax constituted 2.52% of GDP, which is higher than the Organization of Economic Cooperation and Development (OCED) 's average of 1.54% (Berry, 2019). Fourth, Sweden is among the emerging economies that have successfully achieved economic transition to the service-driven phase. This is evident from the country's sectoral contribution to GDP, entailing agriculture (1.6%), industry (33%), and service (65.4%) (Crawford & Nilsson). Consequently, structural change in Sweden is environmentally friendly and promotes decarbonization due to the prevalent contributions of the service sector. Given the prevailing statistical facts on the Swedish economy, it is not strange that the recently evolving empirical studies are advancing the country among the most sustainable economies globally. Besides, the 2020 environmental sustainability index ranks Sweden first among 180 economies globally (Heshmati and Rashidghalam, 2021). Hence, conducting an empirical inquiry into the driving factors of a sustainable environment in Sweden remains a viable and plausible research scope. This is so as the various emanating policies will serve as a workable model for other service-driven economies that are still encountering environmental issues and set the pace for the emerging industrial-driven economies.

Against the backdrop of the foregoing, the current paper pursues to investigate the nexuses among structural change, disintegrated energy consumption, and carbon emissions in Sweden. The rationale for this study lies in the dearth of literature on the highlighted nexuses despite the evolving studies on Sweden. To the best of our knowledge, we are unaware of any study examining the impacts of structural change and disaggregated energy on CO_2 in Sweden. To this end, this study will constitute the first strand of empirical verification affirming or refuting the perceived effects of a service-driven economy on carbon emissions in Sweden. Further, despite the transition from fossil fuels to nuclear energy and renewable energy in Sweden, the menace of GHG emissions is not totally eradicated. This implies much is left to be desired in the country's journey to a carbon-free environment. Hence, there is a need to assess the individual impacts of renewable energy and non-renewable energy on carbon emissions in Sweden. In addition to the research's motive, the study considers the intervening roles of GDP, trade openness, and financial development in the carbon emissions model of Sweden. Considering the expositions of Grossman and Helpman (1991) on the nexus between income and environmental pollution, it is intuitional to include GDP in the model. An omission of income could result in model misspecification leading to unbiased and inconsistent estimates. Besides, considering the various empirical advances of Sweden as a sustainable economy, it becomes highly pertinent to examine whether increasing the growth rate will escalate or mitigate carbon emissions, although the former is expected.

This study avails the extant literature with three novelties. First, empirical investigations on the mitigating and enhancing factors of CO_2 are at the premature stage for Sweden. This implies little is on records regarding the factors influencing variations in the country's carbon emissions. More empirical-based studies are inevitable to enhance an all-inclusive understanding, of which the present study constitutes a novel scope of research. Second, considering the functional impacts of structural change and disintegrated energy on CO_2 in Sweden is largely neglected in the extant studies. This is despite the country's roadmap 2050, which seeks a total transition from non-renewable energy to renewables, which has recorded unprecedented success. Hence, this paper contributes to the frontier of studies on ecological integrity in Sweden by considering the effects of structural change and dissecting the impacts of energy consumption on REC and NREC. Third, the study employs the wavelet-based Granger causality (WGC) test, which extends the conventional Granger causality test (Li et al., 2021). WGC accounts for the issue of multiple time scales in a time series analysis (Zhang et al., 2021). Additionally, the wavelet coherence estimator instantaneously evaluates correlation and causality among the interacting indicators in a model. Another uniqueness of the WGC lies in its resistance to distribution assumption and misspecification in a time series model (Torun et al., 2020). The present paper is the first study that employed WGC in gauging the nexuses among structural change, disintegrated energy consumption, and carbon emissions in Sweden. The rest of this investigation is organized as follows: the stylized facts on variables of interest are presented in section two; section three reviews relevant literature; section four presents the method; section five presents and discusses the results, and section six concludes with policy implications.

2. Stylized facts on principal variables; carbon emissions, structural change, non-renewable and renewable energies Sweden

This section explores a situation analysis of the key variables related to the Swedish economy. This exercise is necessary to enhance an in-depth understanding of the behavior of each indicator which would thus serve as a leveraging point to support the economic intuitions on the functional nexuses among them. Four indicators that constitute the focus of the present study are highlighted thus. Carbon emissions denote environmental measures, and structural change signifies the productive transition of the Swedish economy from agriculture to the industry and service sector. Non-renewable energy represents how the country depends on fossil fuel energy (fuel, natural gas, and coal). Renewable energy represents the stock of solar, hydro, nuclear, and wind energy. Available statistics reveal the trend in carbon emissions shows that Sweden has persistently achieved a significant decrease in carbon emissions in the last five decades. This implies the economy is decarbonizing its environment despite the persistent growth strides, which accentuates its long-term objective of becoming the most sustainable economy globally by 2050 (World Bank, 2020).

The achievement of Sweden in maintaining declining carbon emissions suggests why it tops the global economies in the environmental sustainability index of 2020 (Heshmati and Rashidghalam, 2021). Some of the factors remarkable for the noticeable decline in Sweden's carbon emissions include sturdy ecological policy, the composition of energy resources consumption, the stage of productive capacity, and citizen engagement in the nation's vision. For instance, ecological policies in Sweden are enacted to ensure cautious actions on effective and economic activities relating affecting ozone layer depletion, climate change, urban environmental quality, maintenance of land and water resources, acidification, chemical and nuclear safety, nature protection, and waste management (OECD, 2000). Moreover, the composition of energy consumption is more on clean sources (renewables) and less on dirty sources (fossil fuels). Besides, the economy's productive capacity is supported by the service sector, which has been empirically advanced as a moderator of carbon emissions (Gao et al., 2021; Hou et al., 2021). Lastly, the engagement of citizens in sustainable development plans is a crucial distinctive factor for Sweden, amidst other countries. Assenting to this claim, a report of a European Commission study shows that average Swedes prefer purchasing eco-labelled detergent (Gwozdz et al., 2017). In addition, the recycling policy is well accepted by Swedes, making the economy environmentally conscious with 88% achievement of can and PET bottle recycling (Boesen et al., 2019).

According to World Bank (2020), the state of structural change in Sweden maintains an upward slope contributed by the service sector, thus implying that Sweden is a service-driven economy with the highest contributions in the last five decades. The service sector comprises transport, education, real estate, wholesale and retail, health care, and financial services. The percentage of the service sector to GDP ranges between 55.11% in 1988 and 65.52% in 2019 (World Bank, 2020). These values surpass the combination of what agriculture and industrial sectors contribute.

The trend in non-renewable energy in Sweden maintains a persistent decline in NREC with significant variations over the last five decades (World Bank, 2020). The reduction in NREC in Sweden is a consequence of the government's commitment to phase out fossil fuels in the economy. In 2005, the Swedish government instituted a commission to pilot an all-inclusive roadmap toward reducing fossil fuel and other fossil equivalent resources by 2020. There are equally significant reductions in the components of fossil fuels in Sweden. For instance, coal production was stopped in 2004 while consumption was restricted to the iron and steel sector. According to Milot et al. (2020), coal's contribution to the country's fossil fuels stands at approximately 5% since 1970, while oil consumption has diminished substantially. The authors further explain that gas resources were underdeveloped, making its share in Sweden's final energy consumption estimated at 2%. Based on the preceding statistics, it is thus expected that a declining trend in non-renewable energy consumption in Sweden will be apparent. Another factor propelling the persistent drop in Sweden's non-renewable is the rising renewable energy that has remained a perfect and most effective substitute for non-renewable. The trend in renewable energy is constantly on the rise in Sweden's energy consumption composition (World Bank, 2020). This is not surprising, going by the country's determination to achieve 100% renewable energy usage to phase out non-renewable energy completely.

A significant landmark of achievement was recorded in 2014 when more than 52% of energy sources for transport, heating, cooling, and electrification are from renewable making Sweden. The share of renewable energy sources achieved in 2014 was a transitional increase from the initial 38.7% recorded in 2004, and this puts Sweden ahead of others among the 28 European Union economies (Turksen, 2019). Renewable energy distribution among its various components had hydropower and nuclear plants in the northern and southern regions of Sweden, contributing primarily to the country's power supply in 2019 (Höltinger et al., 2019). The continued achievements in renewable energy utilization saw Sweden launch the world's first electrified road in 2016 (Mutter and Rohracher, 2022).

The preceding statistical and situational analyses of the key indicators for the present study in Sweden lead us to draw three hypothetical deductions. First, the various empirical propositions and advancements about the sustainability of the environment in Sweden correlate with real-time data for the country. Second, there exists an exciting coherence and synergy between Sweden's environmental policy and development plan. This is evident from the complimentary trend in the macroeconomic indicators under consideration. For instance, by economic intuition, a reduction in non-renewable energy should imply more substitutes for it (renewable energy) are consumed. This is precisely apparent in Sweden, where a decreasing trend in non-renewable coincides with increasing renewables. In addition, empirical studies have advanced the moderating role of structural change propelled by the service sector on carbon emissions. Going by this submission, a rising service sector's contribution should result in declining carbon emissions which is the exact scenario depicted by our stylized facts. These revealing facts leave us with no doubt that the Swedish economy is the epitome of what sustainable development connotes. Third, it is pertinent that care must be taken in drawing absolute conclusions based on mere statistical facts without empirical verifications backed by economic theory and intuitions. For these reasons, the subsequent sections of this study will focus on empirically supported evidence validating the nexuses among structural change, disintegrated energy consumption, and carbon emissions in Sweden.

3. Literature review

The steady rise in carbon emissions with the ensuing devastating effects on the ecosystem and threats to humanity's existence has motivated the emergence of empirical studies seeking to proffer the most suitable and practical solution. Consequently, research on environmental quality is increasing, and debates on its subject areas are at the core of policy issues globally. Among many emanating driving factors of carbon emissions from the extant studies, NREC, GDP, REC, STC, and FD are apparent. That notwithstanding, the research into the environmental effects of structural change is in its early stage. To this end, this study reviews empirical studies within the scope of its objectives with a specific focus on energy consumption (renewable and non-renewable energy) and structural change (industrial sector and service sector).

3.1. Energy consumption-carbon emissions nexus

The fundamental role of energy resources in nation-building justifies why it has attracted extensive strands of empirical studies. Besides stimulating economic growth, the role of energy resources in global warming remains a cause for concern among scholars. There are growing advocacies on the need for nations to be conscious of choosing among energy sources due to the disparity in the emanating environmental effects. This divergence is well documented in the literature. For instance, the joint impacts of REC and NREC on CO_2 were evaluated by Nakhli et al. (2022) in the United States. The empirical model considers the additional effect of economic uncertainty to evaluate the changes in carbon emissions. Monthly data from 1985 to 2020 was adopted using the Bootstrap Rolling estimator. The results show unidirectional causality between electricity consumption and economic policy uncertainty. At the same time, bidirectional causality is evident between carbon emissions and economic uncertainty. Similarly, Usman et al. (2022a) probe the extent to which NREC, REC, economic growth, financial development, and trade openness impact carbon emissions in Pakistan. The empirical evidence relies on the ARDL estimator, which provides long-run and short-run parameters. Prominent among the long-term empirical findings reveal enhancing the impact of financial development and renewable energy on environmental quality through their mitigating effect on carbon emissions. Conversely, non-renewable energy, trade openness, and economic growth deteriorate the environment based on their contributions to the surge in carbon emissions. The short-run results are consistent with the long-run estimates in terms of the impacts of NREC, REC, and trade openness. The outcome of the Granger causality reveals unidirectional effects from trade openness, NREC, REC, and GDP to CO_2 in Pakistan.

Focusing on panel economies from developing regions, Djellouli et al. (2022) assess the dynamic association between energy consumption (renewable and non-renewable), foreign direct investment, economic growth, and environmental degradation in 23 selected African economies. The empirical model relies on PMG, MG, and DFE from 2000 to 2015. Based on the empirical outcomes, all the explanatory variables promote carbon emissions except renewable energy, which has a mitigating effect. Besides, the EKC hypothesis is not supported by the empirical results. In contrast, the reported outcomes validate the existence of the Pollution Haven Hypothesis. Similarly, Ajide and Mesagan (2022) investigate the intervening role of capital investment in the nexuses among non-renewable and renewable energy, foreign direct investment, trade openness, and CO_2 in G20 nations from 1990 to 2017. The study's model estimation draws evidence from the PMG estimator after controlling for cross-sectional dependence and slope heterogeneity. The long-run and short-run results reveal that renewable energy moderates carbon emissions, whereas non-renewable energy stimulates it. More so, capital investment's negative and positive effects are apparent in the long and short-run. Additionally, the interaction of capital investment with renewable and non-renewable energy serves as a stimulus to their observable positive and negative impacts on carbon emissions. Furthermore, Islam et al. (2022) reported that while renewable energy supports and drives sustainable development, non-renewable energy hinders it. Besides, financial development and institutional quality turn out as negative predictors of sustainable development in the sample countries. Non-renewable and REC impacts do not change even with changes in the proxy of environmental measures. This submission is evident in the study conducted by Usman et al. (2022b) on the functional effects of natural resources, renewable and non-renewable energy, financial development, and globalization on the ecological footprint in a panel of oil-dependent economies from 1990 to 2018. Findings from the study show that NREC enhances the growth in GDP while renewable energy and globalization mitigate it.

Some empirical studies focus on the role of renewable energy in the carbon emission model due to the rising interest in the transition from dirty energy sources to clean sources driven by renewables. In line with this view, Ehigiamusoe and Dogan (2022) examine the effects of REC, and GDP on $CO_{2,}$ focusing on low-income economies. In addition, to the individual effects, the interactive impacts of renewable energy consumption and real income are examined using estimation techniques that account for the joint issues of cross-sectional dependence and slope heterogeneity. Findings from the study uncover the mitigating impacts of renewable energy on carbon emissions. In contrast, the interactive effects enhance carbon emissions with the variance of renewable energy depending on real income levels. Similarly, Rahman et al. (2022) find renewable energy to be effective in lessening carbon intensity in a panel of the 25 largest emergent economies globally. Contrariwise, energy intensity and financial development increase the stock of carbon intensity. Similar mitigating impacts of renewable energy are reported in Miao et al.'s (2022) findings for the newly industrialized economies. The submission emanates from estimates provided by Moments Quantile Regression (MMQR) estimator with data ranging from 1990 to 2018. The application of MMQR by Sun et al. (2022) on the CO_2-REC nexus in BRICS from 1995 to 2018 confirms previous submissions that renewable energy significantly mitigates carbon emissions. The model's interaction of renewable energy with economic complexity provides consistent moderating impacts on carbon emissions. More so, Suki et al. (2022) equally find empirical evidence supporting the mitigating effects of renewable energy and technological innovations in Malaysia based on bootstrapped autoregressive distributed lag. Interestingly, when individual renewable energy components are considered, the mitigating impacts do not alter. This submission draws evidence from Yu et al. (2022). The authors examine the asymmetric impact of solar energy consumption on carbon emissions top ten abundant economies in solar energy from 1991 to 2018. The outcomes reveal that solar energy lessens carbon emissions in all the quantiles for the majority of the sample countries. The initial submissions on the negative nexus between renewable energy and carbon emissions are corroborated by Sweden-based empirical studies in the most recent times (Adebayo, 2022).

3.2. Structural change-carbon emissions nexus

The need to achieve sustainable development is instigating policy shifts towards production activities that are green growth compliance. Consequently, developed and emergent economies are implementing policy measures that promote the structural shift from an industrial-driven economy to a service-driven economy. Among many other reasons, while the former sector is high-carbon intensive, the latter is advanced as low-carbon intensive. These submissions have motivated evolving empirical studies that offer intensive explanations of the service sector's factors. Despite the scanty nature of the extant studies, this section reviews the most recent and relevant among them.

With a particular focus on asymmetric nexus, Adebayo (2022) examines the extent to which structural change influences the variation in CO_2 in Turkey from 1965 to 2019. The findings confirm that the explanatory variables exert nonlinear effects on carbon emissions. Besides, structural transition in Turkey is noted to positively correlate with improvements in environmental quality due to the mitigating effect of the service sector on carbon emissions. However, economic progress remains a cause for concern due to its unsustainable nature characterized by reliance on fossil fuel energy utilization which is carbon emissions-intensive. The dual technological and structural change effects constitute the key research focus of Huang et al. (2021) for the Chinese economy. Based on yearly data from 2000 to 2016, the findings show that variance in technological adoption coupled with the internal change in the structure of the industrial sector dictates the level of energy demand for China. Demand is more fundamental for the Chinese sustainable environment due to the emanating CO_2 impacts. The research work of Su et al. (2021) reveals that the continued contributions of the tertiary industry could enhance the increase in GDP rate at 5.6% and, at the same time, lessen the surge in carbon emissions. Besides, a 12.41% carbon emissions peak is anticipated according to China's target of 2030. Consequently, speeding up China's economic transformation appears as a viable policy measure toward realizing the predetermined carbon emissions peak, which is conditional to the net-zero targets. Zheng et al. (2021) conducted a firm-level analysis on structural changes in energy resources, focusing on energy service companies (ENSCs) in 29 provinces in the Chinese economy. The results uncover the mitigating effects of ENSCs and urbanization on carbon emissions. Contrarily, industrialization promotes the rise in CO_2.

The critical roles of REC and STC in China's CO_2 constitute the core interest of Jiang et al. (2020). The authors employ empirical data from 2000 to 2018 in examining the nexus. The findings reveal the transition in the energy mix from fossil fuel to renewable energy as the most significant moderator of carbon emissions. Additionally, the role of structural change is well documented, although not with much emphasis. The desire to probe whether technological innovation and structural changes matter in explaining the variation in carbon emissions in Malaysia motivates the research interest of Ali et al. (2020). The study explores annual data straddling 1985 to 2016 while controlling for additional economic growth and energy consumption roles in the empirical model estimated using the ARDL estimator. The results show that structural change in the industrial sector is not significant enough to explain the variations in $CO_{2,}$ while the effects of technological innovation significantly and negatively explain it. Moreover, the EKC hypothesis did not find empirical backing to advance its validity in Malaysia. The research scope of Rauf et al. (2018) covers a wide range of the stages involved in structural changes by considering the agriculture, industrial, and service sectors on carbon emissions in China. In addition, the effects of trade openness, economic growth, urbanization, and financial development are considered in the empirical model from 1968 to 2016 within ARDL bound testing model. The contributions of the three sectors to GDP, trade openness, and energy consumption exacerbate carbon emissions. In contrast, economic growth and urbanization promote environmental quality.

3.3. Gap in literature

The assessment of the extant literature in the preceding paragraphs unveils some notable lacunas that this study fills. First, the existing panel and country-specific studies on the factors driving or inhibiting carbon emissions are yet to clarify the joint impacts of structural change and disintegrated energy consumption, especially in the case of Sweden. Second, the existing studies are filled with inconclusiveness regarding the magnitudes of effects (positive or negative) or economic relevance (significant or insignificant) on the nexuses among structural change, energy resources, and carbon emissions.

4. Theoretical underpinning and methods

4.1. Data and theoretical underpinning

The current empirical analysis tends to assess the coherence and causality between CO_2 and its drivers (financial development, structural change, renewable energy use, non-renewable energy use, trade openness, and economic expansion) in Sweden using a quarterly dataset stretching from 1980Q1 to 2019Q4. The data and source of the parameters mentioned above are shown in Table 1.

Appreciable economic theories have provided significant propositions to illustrate economic transition in three phases: agriculture, industrial, and service. The concentration of productive capacity in each phase determines the extent of ecological degradation due to energy usage intensity. For instance, the production activities centered in the agriculture sector require a low rate of energy consumption due to the labor-intensive nature of production methods in the sector (Das, 2021). This explains why the sector is empirically denoted as low carbon-intensive (Rauf et al., 2018). Moreover, the transition from agriculture to the industrial sector involves massive production requiring increased energy resources, thus leading to higher CO_2 (Yu et al., 2021; Hao et al., 2021). The increasing production volume and the resultant carbon emissions will propel the need for transition to clean and carbon-free productive capacity leading to an eventual transition to the service sector. The production activities in the service sector covering wholesale and retail, financial, and telecommunication services moderate the surge in carbon emissions (Çakar et al., 2021; Hou et al., 2021). Consequently, a structural change concentrated between agriculture and industrial sectors promotes carbon emissions suggesting a direct relationship. Contra-wise, a significant change in the economic structure driven by the service sector mitigates an increase in carbon emissions, implying an inverse relationship.

Table 1. Data sources and measurement.

Symbol	Description	Measurement Unit	Source
TO	Trade Openness	Trade % GDP	WDI
CO_2	Carbon Emissions	Metric tons per Capita (CO_2 emissions)	BP
REC	Renewable Energy	Addition of Solar, Hydro, Nuclear and Wind measured in exajoules	BP
NREC	Non-renewable Energy Use	Addition of Oil, Gas, and Coal measured in exajoules	BP
GDP	Economic Growth	Per capita GDP (constant 2010 US$)	WDI
FD	Financial Development	Domestic credit to private sector (% of GDP)	WDI
STC	Structural Change	Services, value added (% of GDP)	WDI

The relationship between energy consumption and CO_2 is not static, considering the diversity in energy sources. In a case where energy consumption is mainly sourced from fossil fuels, the consequential effects are usually inducing the stock of carbon emissions which implies the existence of positive nexus (Ajide and Mesagan, 2022; Djellouli et al., 2022; Ibrahim and Ajide, 2021). Alternatively, the concentration of energy used in the renewable source serves as a hindrance to the rising carbon emissions bringing about negative connections (Islam et al., 2022; Rahman et al., 2022).

Drawing from the above illustrated theoretical background and relying on the extant literature, specifically Ali et al. (2020), with modifications to suit the objective of this study, the empirical function is given as follows, indicated in Eq. (1).

$$CO_{2t} = f(GDP_t,\ REC_t, NREC_t, FD_t, TO_t) \tag{1}$$

4.2. Theoretical framework

The economic intuitions guiding the direction of impact of the outcome variable and each of the regressors are illustrated in this section. These relationships are explained in accordance with the theoretical underpinning and empirical submissions from the previous studies. Starting with structural change, since the Swedish economy is service-driven, it is expected that structural change STC in the economy reduces carbon emissions (CO_2). The main reason for hypothesizing mitigating STC-carbon emissions is due to the relative role of the service sector in moderating environmental pollution (Çakar et al., 2021; Hou et al., 2021). Hence, a negative sign is expected in the STC-CO_2 nexus. The relationship between renewable energy (REC) and carbon emissions has been empirically confirmed to be in the reverse order. This is because renewable energy promotes economic progress without contributing to environmental degradation (Ibrahim and Ajide, 2021; Kirikkaleli and Adebayo, 2021). Consequently, a negative interlock is anticipated. Non-renewable (NREC) is carbon-intensive due to fossil fuels that constitute its primary source. A large chunk of empirical evidence found that NREC promotes carbon emissions (Nakhli et al., 2022; Akadiri et al., 2022; Asiedu et al., 2021). Therefore, we anticipate NREC to promote CO_2. The rapid rate of technological advancement and continued improvements in globalization have opened many economies to the international community. Besides, the assumption that open economies perform better and grow faster than closed economies, coupled with the technology transfer has motivated extensive openness in the present era (Ibrahim and Ajide, 2021). However, openness to trade can serve as moderating factor to carbon emissions due to the technology transfer and knowledge diffusion involved suggesting a negative nexus between trade openness and carbon emissions (Dauda et al., 2021). On the other hand, carbon emissions shifting from industrialized to less developed economies based on the pollution haven hypothesis (PHH) would imply trade openness promotes carbon emissions (Musah et al., 2021; Wang and Zhang, 2021). As such, both positive and negative signs are anticipated. Financial development nexus with carbon emissions can either enhance or hinder carbon emissions. The reason is that improved services can strengthen the inclusiveness of more people financially, allowing poor citizens to purchase other energy-intensive products. Besides, the financial intermediation that promotes access to technology and low carbon-intensive products can be highly useful in mitigating carbon emissions. Consequent to the foregoing, some studies provide empirical submissions supporting the inducing effects of financial development (FD) on carbon emissions (Ling et al., 2021; Sheraz et al., 2021; Yao and Zhang, 2021), while others posit otherwise (Khan et al., 2021). Based on these views, both positive and negative signs are hypothesized. Regarding the nexus between economic growth and carbon emissions, three positive and negative signs are hypothesized following extant studies (Kirikkaleli et al., 2021; Salari et al., 2021).

Table 2. Descriptive statistics.

	CO_2	GDP	NREC	REC	STC	TO	FD
Mean	6.1580	44318.9	251.24	377.62	60.499	72.849	75.468
Median	6.3766	44046.7	245.24	388.56	60.457	75.155	51.034
Maximum	8.6418	58032.3	408.52	439.71	65.714	93.547	131.99
Minimum	4.1828	31308.1	188.35	216.88	55.071	49.691	30.957
Std. Dev.	1.1053	8857.4	45.428	43.491	3.3340	12.559	40.271
Skewness	-0.1596	0.1025	0.9470	-1.6372	0.0257	-0.1912	0.2669
Kurtosis	2.5441	1.5060	4.0100	5.4961	1.7901	1.6549	1.2946
Jarque-Bera	2.0646	15.160	30.720	113.02	9.7759	13.036	21.288
Probability	0.3561	0.0005	0.0000	0.0000	0.0075	0.0014	0.0000
Obs	160	160	160	160	160	160	160

Table 3. Correlation matrix.

Variables	CO_2	GDP	NREC	REC	STC	TO	FD
CO_2	1						
GDP	-0.9237*	1					
NREC	0.9264*	-0.8270*	1				
REC	-0.6351*	0.5686*	-0.7459*	1			
STC	-0.8992*	0.9297*	-0.8281*	0.4496*	1		
TO	-0.7921*	0.9147*	-0.6957*	0.4562*	0.8395*	1	
FD	-0.8798*	0.9448*	-0.7414*	0.4012*	0.8974*	0.8258*	1

4.3. Methodology

By expanding the inquiry into Sweden, this study effort adds to the ecological literature by employing a unique approach. This analysis finds a time-frequency interrelationship between CO_2 and REC, STC, NREC, TO, and GDP. For this objective, the wavelet coherency (WTC) with phase differences developed by (Goupillaud et al., 1984) was used. The wavelet analysis reveals the spectral structure of the time series, specifically how numerous periodic features of the time series alter with time. The wavelet transformation technique divides the time series into various frequencies. In this study, the Morlet wavelet function was utilized because it offers an adequate balance between time and frequency, which are the two key components of any wavelet analysis. The Morlet wavelet function has the following form Eq. (2):

$$\varpi(t)\pi^{-\frac{1}{4}}e^{-i\varpi t}e^{-\frac{1}{2}t^2} \tag{2}$$

Where: i is $\sqrt{-1}$, and e depicts the non-dimensional frequency. According to (Awosusi et al., 2021), continuous wavelet transformation is beneficial for obtaining time-series characteristics. Arshian et al. (2021) also found that the CWT aids XWT analysis in determining the time-frequency interrelationship between variables. The CWT is depicted as Eq. (3):

$$\varpi_{k,f}(s) = \frac{\rho t}{\sqrt{s}} \sum_{n'=0}^{N-1} x_{n'} \varpi^*\left((n' - m)\frac{\rho t}{s}\right),\ with m = 0, 1, 2, .., .., .., N-1 \tag{3}$$

$|W_n^x(s)|^2$ depicts the WPS, which reveals the variance of the time series. The influence of the observations is represented as a cone of influence. The power spectrum is constructed as Eq. (4):

$$D\left(\frac{|W_n^x(s)|^2}{\theta_x^2} < p\right) = \frac{1}{2}P_f X_v^2, \tag{4}$$

Where: Fourier frequency depicts with the scale of the mean spectrum (P_f). θ represents variance, and X^2 illustrates the two series. p is less than P_f, when 1 is real wavelets and 2 is the complex wavelets for v. The co-movement of the two-time series (p,q) was investigated using the wavelet coherence, is formed as shown in Eq. (5):

$$R_n(s) = \frac{\left|S\left(s^{-1}W_n^{pq}(s)\right)\right|^2}{S\left(s^{-1}\left|W_n^p\right|^{\frac{1}{2}}\right)S\left(s^{-1}\left|W_n^q\right|^{\frac{1}{2}}\right)} \tag{5}$$

Where: S depicts the smoothing operator for time and scale. The phase difference (φ_{pq}) of series (p,q) is investigated in the wavelet coherence, which is formed as shown in Eq. (6):

Table 4. Unit root test.

	ADF		PP		ZA			
Variables	Level	*FD*	Level	*FD*	Level	*BD*	FD	*BD*
CO_2	-1.7022	-6.2639*	-2.6894	-5.9883*	-4.708	2001Q1	-5.739*	2004Q2
GDP	-2.2638	-5.7965*	-2.0675	-5.6914*	-3.7339	1998Q1	-5.1960**	1993Q2
FD	-2.5964	-4.2782*	-1.8970	-6.2839*	-5.958*	2000Q3	-6.2647*	2000Q2
REC	-3.0670	-5.9451*	-2.6085	-6.3050*	-3.3935	2001Q2	-6.3913*	2003Q3
NREC	-2.2518	-4.2887*	-2.3401	-6.0333*	-4.0575	2012Q1	-5.2102**	1991Q4
STC	-2.8763	-4.7817*	-2.7892	-5.7010*	-3.6509	1989Q2	-5.5181**	1993Q2
TO	-2.5549	-4.2997*	-2.1685	-5.8870*	-3.5276	1993Q1	-5.628**	1992Q2

Note: 10%, 5% and 1% are illustrated by ***, ** and *. FD denote first difference.

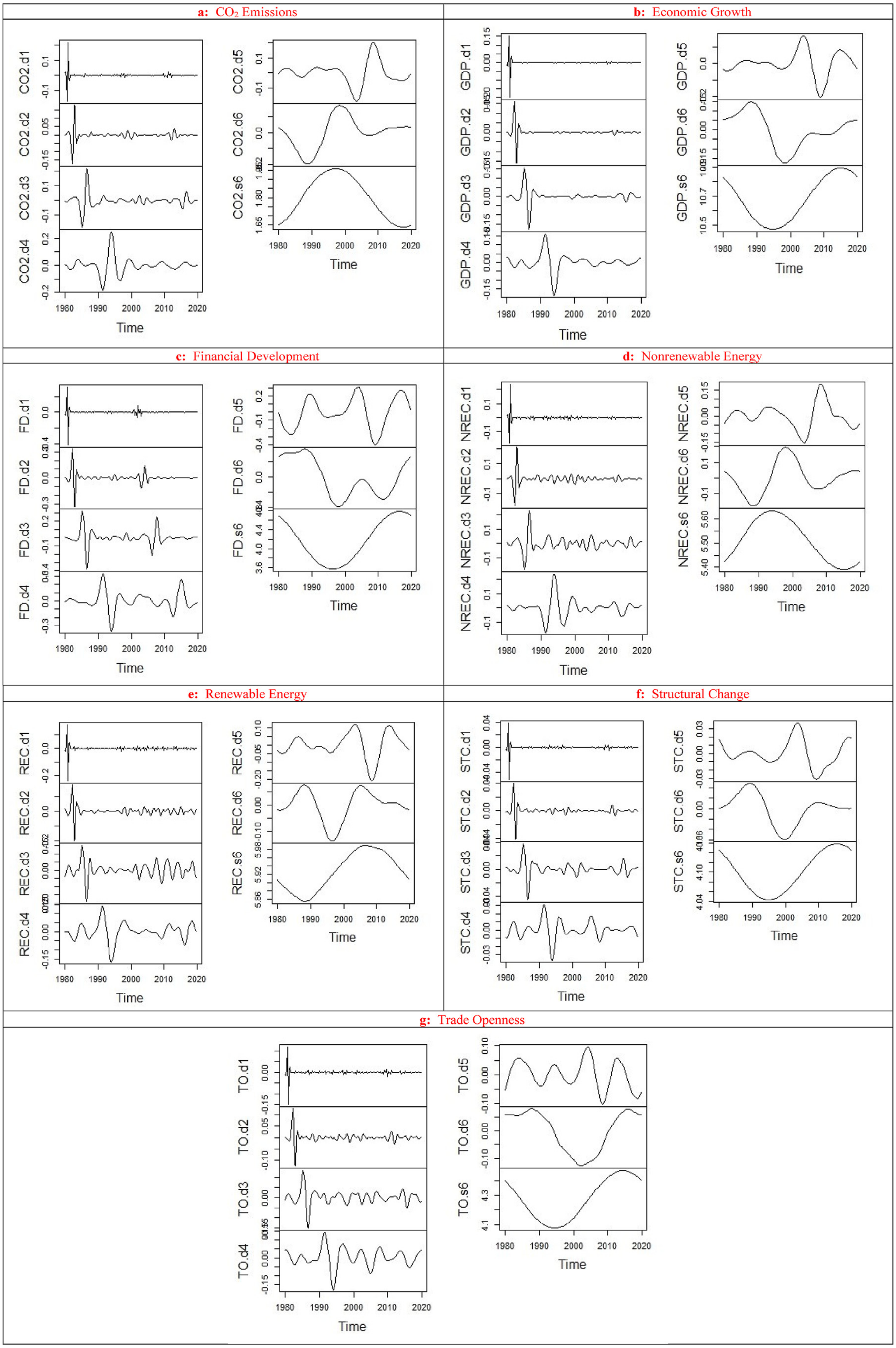

Figure 1. a CO_2 Emissions; b: Economic Growth; c Financial Development; d Nonrenewable Energy; e Renewable Energy; f Structural Change; g Trade Openness.

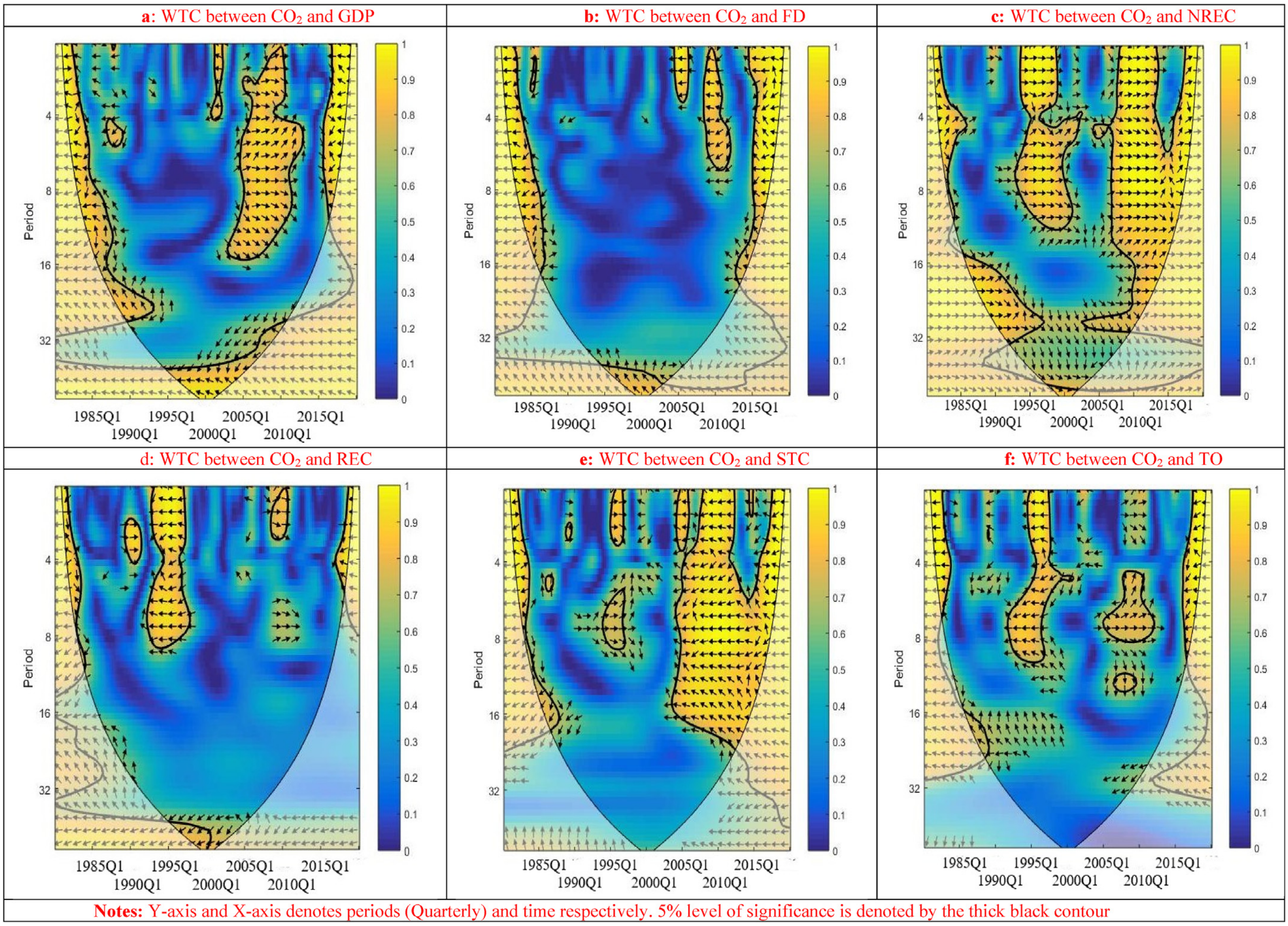

Figure 2. Notes: Y-axis and X-axis denotes periods (Quarterly) and time respectively. 5% level of significance is denoted by the thick black contour. a WTC between CO_2 and GDP; b WTC between CO_2 and FD; c WTC between CO_2 and NREC; d WTC between CO_2 and REC; e WTC between CO_2 and STC; f WTC between CO_2 and TO.

$$\varphi_{pq} = \tan^{-1}\left(\frac{L\{W_n^{pq}\}}{O\{W_n^{pq}\}}\right) and \varphi_{pq} \in [-\pi, \pi], \qquad (6)$$

Where: the imaginary and real component operators are denoted by O and L, respectively. p leads q, when $\varphi_{pq} \in \left[0, \frac{\pi}{2}\right]$ but q leads p, when $\varphi_{pq} \in \left[-\frac{\pi}{2}, 0\right]$ correspondingly. Alternatively, the anti-phase difference also occurs for the series. Where p leads q, when $\varphi_{pq} \in \left[-\pi, -\frac{\pi}{2}\right]$ but q leads p, when $\varphi_{pq} \in \left[\frac{\pi}{2}, \pi\right]$ correspondingly.

5. Findings and discussions

5.1. Preliminary test outcomes

In this paper, we tend to assess the time-frequency analysis between CO_2 emissions and their drivers. The research commenced by presenting short information on the variables of research, as disclosed in Table 2. The mean of GDP (44318.9) is the highest, which ranges from 31308.1 and 58032.3. This is accompanied by REC (377.62) which falls between 216.88 and 439.71, NREC (251.24), which ranges from 188.35 to 408.52, FD (75.468), which ranges from 30.957 to 131.99, TO (72.849), which falls between 49.691 and 93.547 and CO_2 (6.1580) which ranges between 4.1828 and 8.6418. The kurtosis values exposed that CO_2, GDP, STC, TO and FD are platykurtic while NREC, and REC leptokurtic. Moreover, the skewness values disclosed that CO_2, REC and FD are skewed negatively while GDP, STC, TO and NREC are positively skewed. The Jarque-Bera values disclosed that GDP, STC, TO, REC, NREC and NREC are nonlinear. Based on this logic, using linear techniques will present outcomes that are disingenuous.

5.2. Correlation and unit root outcomes

Table 3 presents the correlation matrix between CO_2 and GDP, STC, TO, REC, NREC, and NREC. The outcomes show significant correction among the parameters of the investigation. Furthermore, we explore the order of integration of the study's parameters. In doing so, we applied two conventional unit root tests (ADF and PP). The outcomes of the PP and ADF disclosed that CO_2 GDP, STC, TO, REC, FD and NREC are non-stationary at the level; however, after the first difference is taken GDP, STC, TO, REC, NREC and NREC are stationary (see Table 4). According to Awosusi et al. (2022), if there is proof of break(s), the traditional tests (PP and ADF) will produce distorted outcomes. As a result, we utilized the ZA unit root test to identify both break and variables stationarity attributes. The ZA outcomes disclosed that only FD is stationary at level; however, after the first difference is taken GDP, STC, TO, REC, NREC and NREC are stationary (see Table 4).

Note: * represents P<1%

5.3. Wavelet decomposition outcomes

In the empirical literature, scant works have been conducted to explore the interrelationship between CO_2 and its drivers in Sweden. Mustacao (2018) and According to Arshian et al. (2017), there are

Table 5. Wavelet-based granger causality outcomes.

Frequency Domain	Dependent Variables	Independent Variables						
		CO_2	GDP	FD	REC	NREC	STC	TO
D1	CO_2	-	11.098**	1.2919	1.2929	12.686**	27.284*	16.550*
	GDP	7.1984	-	0.8422	1.2435	7.9667	12.427**	18.704*
	FD	1.7651	2.7391	-	0.2071	2.4842	7.2444	15.600*
	REC	0.7867	7.4102	0.2956	-	2.7345	1.5413	0.3859
	NREC	8.7044	12.029**	2.5986	0.4735	-	6.2157	19.883*
	STC	0.3094	7.9778	0.9115	2.6494	2.6144	-	4.0615
	TO	3.5704	22.924*	2.3412	2.0701	4.8636	2.1690	-
D2	CO_2	-	12.918**	1.8183	2.4783	12.837**	10.910**	13.754**
	GDP	8.1792	-	1.7885	2.1350	13.226**	0.5207	1.8010
	FD	9.3410***	1.7600	-	2.1065	14.008**	0.5520	0.5536
	REC	6.3250	3.1195	2.0273		11.091**	0.2573	0.7297
	NREC	7.7233	3.2360	2.0526	2.1577	-	0.6205	1.2674
	STC	7.9840	2.3135	1.9177	3.5365	11.907**	-	1.3766
	TO	6.7393	3.8980	1.8680	1.6409	11.505**	0.6039	-
D3	CO_2	-	12.086**	4.9182	7.9355	4.4693	7.5006	9.2965***
	GDP	7.1617	-	3.5590	7.2570	4.8785	9.9786***	5.5637
	FD	4.8591	7.0919	-	7.2570	4.2132	5.4104	4.5923
	REC	4.9096	4.1484	3.9807	-	3.1812	5.6775	2.5232
	NREC	7.3275	9.4244***	6.3610	9.1567	-	8.0226	7.8761
	STC	8.2631	9.0369	4.6638	7.9779	5.3386	-	9.1132
	TO	6.2332	5.0232	4.5170	8.1124	3.0037	8.5456	-
D4	CO_2	-	20.997*	12.995**	5.4357	16.789*	36.203*	37.495*
	GDP	19.674*		12.567**	8.2216	16.943*	30.282*	25.419*
	FD	17.875*	33.708*	-	19.543*	20.045*	44.264*	33.284
	REC	17.932*	46.432*	22.152*	-	42.893*	34.616*	38.435*
	NREC	27.017*	25.309*	21.366*	8.4328	-	37.188*	46.964*
	STC	10.142***	10.236***	4.4854	1.7089	6.6410	-	26.320*
	TO	25.535*	24.661*	23.034*	12.534**	29.726*	29.519*	-
D5	CO_2	-	64.108*	53.435*	50.528*	90.227*	104.92*	134.75*
	GDP	63.800	-	61.716*	57.300*	79.051*	103.30*	111.99*
	FD	51.155*	35.403*	-	42.142*	56.510*	70.755*	71.323*
	REC	62.384*	75.540*	73.394*	-	78.365*	80.201*	122.07*
	NREC	83.327*	73.040*	70.876*	59.465*	-	111.34*	132.99*
	STC	65.292*	41.660*	38.751*	36.411*	63.458*	-	87.318*
	TO	64.406*	78.307*	69.333*	74.518*	91.151*	122.80*	-
D6	CO_2	-	24.433*	99.430*	35.880*	71.227*	103.70*	70.340*
	GDP	11.358**	-	23.958*	21.110*	11.720**	6.5028	16.622*
	FD	15.561*	28.275*	-	34.271*	83.182*	86.671*	52.019*
	REC	22.621*	21.503*	64.383*	-	88.022*	72.444*	36.015*
	NREC	55.018*	26.594*	104.90*	27.080*	-	105.55*	79.426*
	STC	69.969*	20.443*	106.76*	44.829*	65.342*	-	68.691*
	TO	31.632*	22.776*	85.893*	19.300*	68.775*	81.749*	-
Original	CO_2	-	19.921*	2.8196	3.5612	4.9296	31.522*	12.163**
	GDP	3.6191	-	0.7184	6.0494	5.2993	24.136*	20.105
	FD	13.873**	4.3209	-	6.3716	27.439*	7.0760	10.903***
	REC	4.8212	22.209*	9.0150	-	6.2049	10.771***	2.0520
	NREC	6.3419	21.902*	4.1963	2.5762	-	25.391	2.8214
	STC	11.716**	1.5028	1.8859	3.7960	6.6469	-	2.0939
	TO	8.0379	12.083**	7.5669	3.5670	6.1915	12.028**	-

Notes: D1-D2, D3-D4 and D5-D6 stands for short, medium and long-term respectively. *, ** and *** denotes $P<1\%$, $P<5\%$ and $P<10\%$. Chi-square value are reported.

various periods in datasets of distinct variables, and not just the two can reflect the relevant time scales in the specific study. As a result, to assess the interrelationship between CO_2 and GDP, STC, TO, REC, FD and NREC, we utilize time–frequency-based technique 'wavelets' to examine the time series dissimilar time horizons. Non-stationarity is treated as an inherent quality of data by Wavelets rather than an issue that can be remedied by data pre-processing. Figure 1 (a-g) shows MRA[1] of order $J = 6$ for CO_2 and GDP, STC, TO, REC, FD and NREC by utilizing the

[1] multi-resolution analysis.

MODWT[2] centered upon the least asymmetric (*LA*) wavelet filter initiated by Daubechies (1992). In Figure 4 (a-g), the orthogonal parts (D_1, D_2,..., D_6) are plotted to display the dissimilar frequency parts of the real variable and a smoothed part (S_6). Furthermore, over longer periods, the fluctuation in CO_2, GDP, STC, TO, REC, FD and NREC becomes more stable. When explaining the movements, four main periods are used namely, $D_1 + D_2$ which depicts the short-run, $D_3 + D_4$ signifies the medium-run, $D_5 + D_6$ which stands for long-run and (S_6), which denotes very long-run.

5.4. Wavelet coherence outcomes

We use the wavelet coherence (WTC) to inspect the relationship between the variables after decomposing the wavelet time series data of the variables under study (WTC). The yellow color depicts strong coherence between two variables, while the blue color shows weak coherence between the series. The right and left arrows shows depict positive and negative coherence between variables. Moreover, the right-up/leftward-down disclose that the second variable lead/cause the variable first variable. In addition, the right-down/left-up arrows disclosed that the first variable lead/cause the second variable. Figure 2(a-f) shows the Wavelet Coherence Transformation displaying the sectors where the two-time series demonstrate co-movement in the time and frequency domain.

Figure 2a presents the WTC between GDP and CO_2 between 1980Q1 and 2019Q4. In the periods 0–32 quarterly from 1981-1990, left-down arrows surfaced, which illustrates the negative interrelationship between GDP and CO_2 with GDP leading. In addition, between 2000 and 2010 quarterly at the period of scale 0–16, GDP drives CO_2 positively with CO_2 leading between 2000 and 2010. Furthermore, a period of scale 0–32 quarterly, the arrows are left-up, which illustrates that CO_2 and GDP are out-of phase, i.e., negative coherence between CO_2 and GDP from 2015-2019 with CO_2 leading. In summary, we established a negative coherence between $_{CO2}$ and GDP. These outcomes show that in the short and long-term, economic expansion enhances the quality of the environment in Sweden. This implies that Sweden is in the composition and technique stages, where it gives attention to the quality of the environment. This further resonates with the fact that Sweden is on the path to achieving its SDGs. This outcome affirms the studies of Usman et al. (2020). Nevertheless, this outcome contradicts the findings of Akadiri et al. (2021) and Usman et al. (2021).

Figure 2b presents the WTC between CO_2 and FD between 1980Q1 and 2019Q4. The majority of the arrows are left-up at the period of scale 0–32 quarterly between 1982 and 1978 with FD leading CO_2 between CO_2 and FD from 1980 to 2019. In addition, at the period of scale 32 quarterly, the arrows are left-up, implying that CO_2 and FD are out-of-phase with CO_2 leading. Moreover, from 2010-2018, at the period of scale 0–32 quarterly, the arrows are left-down, demonstrating that CO_2 and FD are out-of-phase. In summary, we established negative coherence between FD and CO_2, with FD leading CO_2. This implies that financial development enhances the quality of the environment in the short-long-term. This further discloses that Sweden's financial sector is at a mature stage. At this stage, the financial sector also plays a vital role in regulatory contamination of the environment by boosting technological progress in the supply of energy to lessen the emissions level (Kirikkaleli and Adebayo, 2021). This designates that FD, which echoes the real accessibility of financial assets by stock markets and banks for activities that are productive and funding networks for projects, can play a substantial role in curbing emissions, majorly by lessening emissions of CO_2. Hence, FD lessens the destruction of the environment. In addition, FD will usually start R&D, deepen economic operations, and entice FDI to have an influence on the sustainability of the environment via investment in renewable energy projects (Kihombo et al., 2021). This outcome complies with the studies of Kirikkaleli and Adebayo (2021) and Kihombo et al. (2021), who reported that financial development boosts the sustainability of the environment. However, the result contradicts the studies of Shahbaz, Haouas, Sohag, and Ozturk (2020), Shoaib, Rafique, Nadeem, and Huang (2020) and Wang, Mirza, Vasbieva, Abbas, and Xiong (2020) who established that FD harm quality of the environment.

Figure 2c presents the WTC between CO_2 and NREC from 1980Q1-2019Q4. Between 1981 and 2018, the majority of the arrows are right-up at the period of scale 0–32 quarterly suggesting an in-phase interrelationship between NREC and CO_2 with NREC leading in the majority of the sub-periods. This implies that NREC contributes to the destruction of the environment in Sweden in the short-log-term. This outcome is not surprising given the fact that nations overwhelmingly rely on the fossil fuels for accomplishing their economic expansion. As a consequence of this inevitable consumption, global pollution levels are increasing. Likewise, the studies of He et al. (2022) for Colombia and Fatima et al. (2021) for high emitter countries conveyed similar findings.

Figure 2d depicts the WTC between CO_2 and REC from 1980Q1-2019Q4. The majority of the arrows are left-down from 1982-1984, 1993 and 1997, and 2016–2018 at the period of scale 0–8 quarterly, which implies out-of-phase interconnection between CO_2 and REC with REC leading CO_2 in these sub-periods. Regarding the effect of REC on CO_2, the outcomes of this research provide that REC negatively drive CO_2 emissions in the middle and short-term. This undoubtedly indicates the environmentally-friendly role of REC in curbing CO_2 signifying the right route for Sweden in attaining SDGs by incorporating and progressing green energy technologies. This implies the economy is decarbonizing its environment despite the persistent growth strides, which accentuates its long-term objective of becoming the most sustainable economy globally by 2050. A significant landmark of achievement was recorded in 2014 when more than 52% of energy sources for transport, heating, cooling, and electrification are from renewable sources. The share of renewable energy sources achieved in 2014 was a transitional increase from the initial 38.7% recorded in 2004, and this puts Sweden ahead of others among the 28 European Union economies (Turksen, 2019). Renewable energy distribution among its various components had hydropower and nuclear plants in the northern and southern regions of Sweden, contributing primarily to the country's power supply in 2019 (Höltinger et al., 2019). The continued achievements in renewable energy utilization saw Sweden launch the world's first electrified road in 2016 (Mutter and Rohracher,

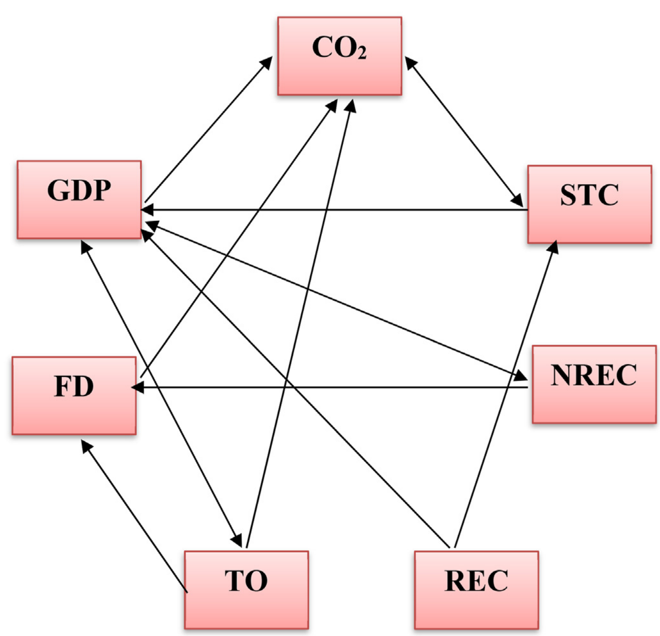

Figure 3. Raw causality between CO_2, FD, GDP, NREC, REC, TO and STC.

[2] maximal overlap discrete wavelet transform.

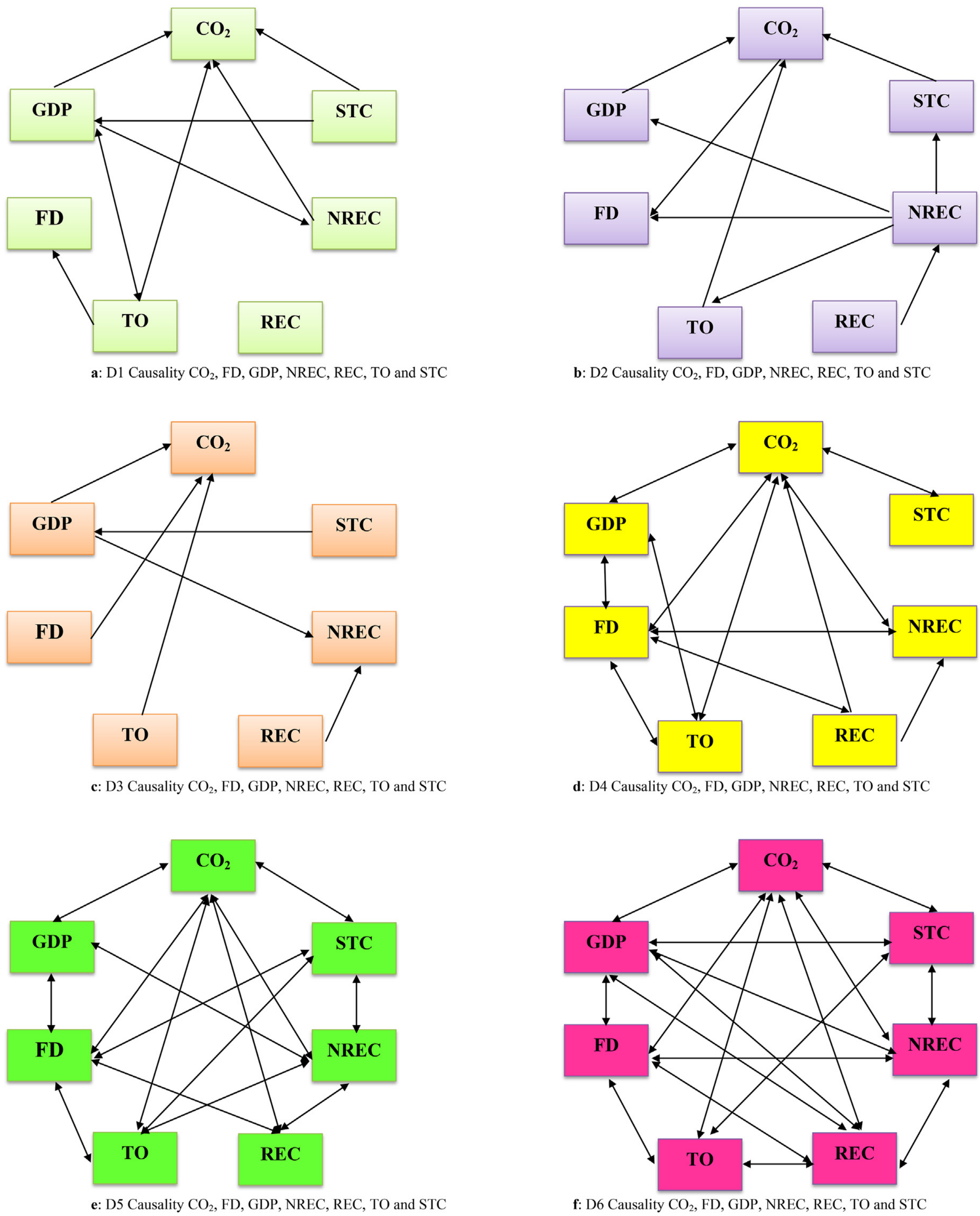

Figure 4. a D1 Causality CO_2, FD, GDP, NREC, REC, TO and STC; b D2 Causality CO_2, FD, GDP, NREC, REC, TO and STC; c D3 Causality CO_2, FD, GDP, NREC, REC, TO and STC; d D4 Causality CO_2, FD, GDP, NREC, REC, TO and STC; e D5 Causality CO_2, FD, GDP, NREC, REC, TO and STC; f D6 Causality CO_2, FD, GDP, NREC, REC, TO and STC.

2022). This outcome complies with the studies of Awosusi et al. (2022), Kirikkaleli and Adebayo (2021), Pata et al. (2021) and Oladipupo et al. (2021), who reported that REC abates emissions.

Figure 2e presents WTC between CO_2 and STC from 1980Q1 to 2019Q4. The majority of the arrows are left-down from 1982-1985 and 2003–2018 at the period of scale 0–16 quarterly, which implies out-of-phase interconnection between CO2 and STC with STC leading CO2 in the majority of the sub-periods. These outcomes imply that structural transformation in Sweden abate emissions of CO_2 in the short, medium and long-term, respectively. The significance of structural shift is that it permits a country's economy to switch from agriculture which is low-polluting to the secondary industry, which is high-polluting, and revert to the tertiary sector, which is lower polluting. This is not surprising given the fact that the service sector in Sweden has witnessed an upward slope. The figure implies that Sweden is a service-driven economy with the highest contributions in the last five decades. The service sector comprises transport, education, real estate, wholesale and retail, health care, and financial services. The percentage of the service sector to GDP ranges between 55.11% in 1988 and 65.52% in 2019 (World Bank, 2020). Since the service sector consumes less energy compared to other sectors, its effect on the environment in Sweden is as anticipated. The studies of Villanthenkodath et al. (2021), and Wang, Z., Rasool, Zhang, Ahmed and Wang (2020) reported similar findings.

Lastly, Figure 2f presents the WTC between CO_2 and TO between 1980Q1 and 2019Q4. In the periods 0–32 quarterly from 1981-1985, left-up arrows surfaced, illustrating the negative interrelationship between TO and CO_2 with CO_2 leading. In addition, between 1992 and 1998, quarterly at the period of scale 0–16, TO drive CO_2 negatively, with CO_2 leading between 1992 and 1998. Furthermore, at the period of scale 0–32 quarterly, most of the arrows are left-up, illustrating that TO and GDP are out-of-phase, i.e., negative coherence between CO_2 and TO from 2015-2019 with CO_2 leading. In summary, we established a negative coherence between CO_2 and TO. This implies that trade in Sweden is sustainable in the short and long term. This is because developed countries like Sweden have significantly succeeded in developing new technologies in recent decades, and Sweden takes full advantage of the technology spillover effect caused by trade (Oladipupo et al., 2021). This outcome is consistent with prior studies (Kasman and Duman, 2015; Al-mulali and Sheau-Ting, 2014).

5.5. Wavelet-based granger causality outcomes

After establishing the coherence and lead/lag association between CO_2 and its drivers, we applied the wavelet-based Granger causality (WGC) as a robustness check for the wavelet coherence to capture the causal interconnection between CO_2, STC, FD, GDP, TO NREC, and REC. The GWC test, based on MODWT, allows us to determine causality between CO_2, STC, FD, GDP, TO NREC and REC at low, middle and high frequencies, respectively. The WGC accounts for the issue of multiple time scales in a time series analysis (Zhang et al., 2021). Another uniqueness of the WGC lies in its resistance to distribution assumption and misspecification in a time series model (Torun et al., 2020). Table 5 and Figure 3 present the WGC outcomes. The outcomes of the raw series disclosed a one-way causal interrelationship from structural change and financial development to CO_2 emissions. Furthermore, trade openness and renewable energy use Granger cause economic growth. In addition, renewable energy and economic growth can predict structural change. Lastly, financial development can predict trade openness.

Table 5 and Figure 4 (a-f) present the outcomes based on MODWT which disclosed significant causality between CO2 and GDP, REC, NREC, TO and STC mostly in the medium and long-term. These outcomes confirm the wavelet coherence, which uncovers significant coherence and lead/lag association between CO_2 and its drivers. The studies of Awosusi et al. (2022), Akadiri et al. (2021) and Usman et al. (2021), Pata et al. (2021) and Oladipupo et al. (2021) who reported that economic expansion, renewable energy use, financial development, non-renewable energy use and structural change could predict CO2 emissions.

6. Conclusion and policy direction

6.1. Conclusion

In this paper, we assessed the time-frequency analysis interrelationship between CO_2 emissions and financial development, economic growth, renewable energy use, structural change and non-renewable energy use in Sweden. We utilized a yearly dataset stretching from 1980-2019. In order to unlock these interrelationships, we leverage wavelet tools (wavelet-based Granger causality and wavelet coherence). The wavelet-based Granger causality (WGC) test extends the conventional Granger causality test. WGC accounts for the issue of multiple time scales in a time series analysis. Another uniqueness of the WGC lies in its resistance to distribution assumption and misspecification in a time series model. Additionally, the wavelet coherence estimator instantaneously evaluates correlation and causality among the interacting indicators in a model. To the authors' understanding, no research has employed the WGC in gauging the nexuses among structural change, disintegrated energy consumption, and carbon emissions in Sweden. The outcomes of the wavelet coherence disclosed: (a) a negative interrelationship between economic growth and CO_2 emissions in all frequencies; (b) a negative coherence between renewable energy use and CO_2 at middle and high frequencies; (c) a negative co-movement structural change and CO_2 in all frequencies; (d) a positive interrelationship between CO_2 and non-renewable energy use in all frequencies; (e) a negative coherence surfaces between trade openness and CO_2 at all frequencies; and (f) a negative connection between financial development and CO_2 in all frequencies. Moreover, the outcomes of the WGC show that all the variables can predict each other mostly in the long-term.

7.1. Policy recommendations

Based on the above findings, the following suggestions were initiated. Firstly, policy measures are required in the short and long-term. As a result, policymakers in Sweden should focus more on improving public understanding of renewable energy and environmental preservation. Furthermore, the Swedish government should make an effort to participate in the production of non-energy consuming and ecologically friendly products, pressuring polluting enterprises to migrate to countries with less stringent ecological rules. Sweden will profit greatly from greater trade with other nations in this direction as a result of this endeavor. Moreover, since trade boosts the quality of the environment in the short and medium-term, it is essential to utilize trade to boost non-polluting enterprises by imposing taxes on industries that are polluting and providing incentives to industries that are non-polluting to permit producers to switch to cleaner and more environmentally friendly sustainable industries. The recent findings show that substantial resources should be allocated to the research of renewable energy sources in order to curb Sweden's existing over-reliance on fossil fuels since renewable energy helps to mitigate environmental deterioration. Since financial development boosts the quality of the environment, it can perform an essential and constructive role in enhancing Sweden quality of the environment in Sweden in the short, medium and long-term, as the financial sector expansion can boost additional borrowing at reduced. In such a scenario, when taking into account probable CO_2 forecasts, policymakers in Sweden consider the implication of financial development in addition to other drivers of income and energy to improve the quality of the environment, particularly in regard to accomplishing SDGs. Structural change boosts the quality of the environment. Therefore, ecosystem degradation can be lessened in the short, middle and long-term by highlighting tertiary sector activities over secondary sector activities. As a result, we believe that Sweden's shift to service-sector-led growth will help to safeguard the environment. Moreover, service sector-related trade promotion initiatives, Service sector business subsidies, and international service sector cooperation should all be fostered in Sweden. The service industry is essential to every nation's economy since it contributes significantly and quickly to economic growth and job creation. Additionally, the government of Sweden must encourage the expansion of the service industry, and private and public sector participation in service sector advancement is vital for future development. The Swedish economy can reach greater environmental quality by implementing policies based on structural change results.

Declarations

Author contribution statement

Tomiwa Adebayo: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ridwan Ibrahim: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Ephraim Agyekum: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Salah Kamel, Hossam Zawbaa: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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