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Unpacking Türkiye's Trilateral Trade-Off: Export Quality, Growth, and Carbon Emissions¹**Aslı Özen Atabey / Assoc. Prof. Dr.**Kahramanmaraş Sütçü İmam University, Ministry of National Education Financial Affairs Manager
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Abstract

Export quality, economic growth, and carbon emissions are key elements in the discourse on sustainable development, particularly for developing economies. This study explores the dynamic relationships among these variables in Türkiye over the period 1963–2023. Using annual data on GDP, the Export Quality Index (EQI), and CO₂ emissions, the analysis employs the Fourier Toda-Yamamoto (FTY) causality test and continuous wavelet transform (CWT) to capture both temporal causality and time–frequency correlations. The research addresses a substantial theoretical challenge, as the nonlinear and time-varying nature of these trilateral relationships cannot be adequately captured by traditional models. By integrating FTY and wavelet analysis, the study offers a robust and flexible framework that overcomes key empirical limitations and provides time-sensitive insights for policymakers aiming to align export-led growth with environmental sustainability. Empirical results show no direct causality

between export quality and either GDP or carbon emissions. However, a strong bidirectional causality exists between economic growth and emissions. Wavelet analysis reveals positive, time-varying correlations between export quality and both GDP and emissions, particularly during 1963–1980 and 2000–2013. These findings suggest that improvements in export quality have contributed to economic growth and environmental pressures during certain periods, though their long-term effects remain complex and context-dependent. Overall, the study highlights the importance of integrating environmental considerations into export-oriented growth strategies and which strategies could be adopted.

Keywords: Export Quality, Economic Growth, Carbon Emission, Sustainability, Türkiye.**JEL Codes:** C32, F14, O44, O56

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1. Introduction

Achieving long-term developmental goals in emerging economies is fundamentally contingent upon the successful implementation of structural transformation policies that enhance productivity, diversify the economic base, and promote sustainable growth. So that, export quality vitally arises, as it not only reflects the intricacy of production credentials of a country but also forms its coalescence inside global value catenation. Augmenting export merchantises' quality can conduct to exceptional remunerative benefits by increasing periphery of profit of firms, generating labour as well as broad prosperity. An increase in superior products' worldwide demand boosts the advancement of export volume; accordingly stirring inflows of international funds and promoting gni per capita. Such method generates auxiliary habitat both for savings and investment and so economic proliferation. Howbeit, this high-quality transmit manufacturing necessitates advanced technology embracements and production methods' refinements. Here the technological promotions which are commonly guided by R&D investments increases is crucial to nurture innovation, enhance competitiveness, and minimize cost of production in time. Nonetheless, here-mentioned elevations can be lead to greater utilization of resources plus output of carbon. So that deepining solicitude about saeculum of both steadiness and sustainability of environment. The creation of superior merchantise generally entails useage of highest-quality raw materials and production procedures refinements, that might commanding waste generation rises, unwittingly. Withal, to be consisted in this competitive global market, companies have to stick multinational peripheral norms to track and to lessen environmental deterioration. Thus, analyzing the vigorous reciprocity among export quality, economic growth, and environmental outcomes is pivotal to compose policy initiatives which manage economic progress and ecological responsibility together. The research query of the paper is to probe the dynamic nexus among export quality (EQ), economic growth (G or GDP), carbon emissions (CE) and their impact on sustainable development. Yet, the scope is to evaluate export quality, economic growth, and carbon emissions over the period 1963–2023 of Türkiye in the context of their interaction. In line with this problem, the aim of the study is to determine whether direct causal relationships exist between these trilaterals employing the FTY causality test, also to analyze how these relationships evolve over time. Additionally, the study seeks to assess the time-varying correlations and the temporal evolution of these interrelations through continuous wavelet analysis.

This study is structured around five associated dimensions. First, it synthesizes the theoretical cornerstones of EQ, emphasizing its role in structural transformation, international competitiveness, and

sustainable development, while evaluating the methodology of the Export Quality Index (EQI). Second, it provides a extensive review of empirical literature that explores the complex and context-dependent trilateral links across countries and time periods. Third, the study sketches an advanced methodological framework employing the Fourier Toda-Yamamoto causality test and continuous wavelet analysis in order to examine the dynamic and potentially non-linear interactions. Finally, the research findings are presented and discussed in relation to existing scholarship, offering refined insights and policy-relevant determinations for intergrating economic advancement with environmental sustainability.

2. Theoretical Background

Policymakers and industry leaders are increasingly focusing on the qualitative transformation of export structures as a tool to support long-term development. Various policy avenues have been identified to this end, including sectoral diversification, targeted resource reallocation, and the systematic enhancement of product quality (Khandelwal, 2010). Improving product quality enables nations to leverage their existing advantages, thereby elevating efficiency levels and increasing export-derived revenues. However, the potential for quality enhancement differs by product category; specifically, finished goods exhibit a greater capacity for quality improvement relative to agricultural products and natural resources (Henn, 2013). To enhance export quality, manufacturers and policymakers can pursue several avenues: (i) bolstering the physical-human capital quality (Hausmann et al., 2006); (ii) optimizing the "Process-Product-Function-Intersection" system within manufacturing lines (Humphrey & Schmitz, 2002); (iii) reducing tariffs and fostering global trade liberalization through comprehensive strategies, including free trade agreements, deeper integration, foreign direct investment flows, and North-trade and South-trade both among and within themselves (Grossman & Krueger, 1991; Anitweiler et al., 2001; Amighini & Sanfilippo, 2014; Fan et al., 2015); (iv) assessing the creation embedding and advantages of sectoral divisions (Hidalgo & Hausmann, 2009; Poncet & Starosta de Waldemar, 2013); and (v) increasing intricacy, instability, and relative advantage within the fabrication sector (Lee, 2010; Krishna & Levchenko, 2013; Maggioni et al., 2016). Notably, the superiority of exported goods particularly relevant to the overhaul of nations at intermediate phases of economic advancement (Gozgor & Can, 2017).

EQI, a pivotal metric for assessing the quality of exported goods, is predicated on various factors, including technical characteristics, durability, reliability, innovativeness, and customer satisfaction associated with products within the export portfolio. The EQI, utilized by the IMF, is computed using unit

values derived from an extensive dataset encompassing 55.8 million observations of trade values and quantities at the 4-digits Standard International Trade Classification (SITC) level. In instances where import quantities for a specific buyer-exporter-product-year combination are reported across multiple unit sets (for example, kilograms and dozens for clothing) within the same 4-digit category, these are classified as distinct "4-digit SITC plus" products to facilitate the acquisition of comparable unit values within the same product category. Consequently, the total number of "4-digit SITC plus" products

identified through this methodology amounts to 835. The quality estimations are derived from this comprehensive trade dataset, leveraging trade prices, values, quantities, and various supplementary information. The estimation methodology primarily bases quality on unit values, incorporating two significant adjustments. Inspired by Hallak's (2006) framework, this approach is a modified version that seeks to eliminate data restrictions. Initially, it is posited that the trade price p_{mxt} (equivalently unit value) for any given product is determined by the following relationship:

$$\ln p_{mxt} = \zeta_0 + \zeta_1 \ln \theta_{mxt} + \zeta_2 \ln y_{xt} + \zeta_3 \ln \text{Dist}_{mx} + \xi_{mxt} \quad (1)$$

In Eq 1, m , x , and t represent the importer, exporter, and temporal dimension, respectively. Price determination is influenced by three key factors: unobserved quality (θ_{mxt}), the per capita income of the exporter (y_{xt}), and the geographical distance sepa-

rating the importer and exporter (Dist_{mx}). According to IMF (2024), to address the disparities in consumer preferences and the costs associated with trade, a quality-enhanced gravity model is constructed for each product category, as delineated in Eq 2.

$$\ln(\text{Imports})_{mxt} = \text{ImFE} + \text{ExFE} + \alpha \ln \text{Dist}_{mx} + \beta l_{mxt} + \delta \ln \theta_{mxt} \ln y_{mt} + \varepsilon_{mxt}$$

In this analytical context, ImFE represents importer fixed effects, encompass factors unique to the importer that influence the studied outcomes, while ExFE denotes exporter fixed effects. Physical distance, a fundamental variable in gravity models of trade, is defined as previously outlined. The matrix of conventional trade determinants, referred as $\mathbf{I}_{mxt}$, includes range of factors traditionally incorporated within gravity models. The exporter-specific quality parameter, θ_{mxt} , encapsulates the quality of the

goods or services produced by the exporter, and is analyzed in conjunction with the importer's per capita income, represented as y_{mt} . A positive coefficient for δ (i.e., $\delta > 0$) indicates that higher income levels are associated with an increased demand for superior-quality goods. By rearranging Eq 1 and Eq 2 and substituting the unobserved quality parameter in the gravity equation with observable parameters, researchers derive the following estimation equation (IMF, 2024):

$$\begin{aligned} \ln(\text{Imports})_{mxt} &= \text{ImFE} + \text{ExFE} + \alpha \ln \text{Dist}_{mx} + \beta l_{mxt} + \zeta'_1 \ln p_{mxt} \ln y_{mt} + \zeta'_2 \ln y_{xt} \ln y_{mt} \\ &+ \zeta'_3 \ln \text{Dist}_{mx} \ln y_{mt} + \xi'_{mxt} \end{aligned} \quad (3)$$

Here $\zeta'_1 = \frac{\delta}{\zeta_1}$, $\zeta'_2 = -\frac{\delta \zeta_2}{\zeta_1}$, ζ'_3 and $\xi'_{mxt} = -\frac{\delta \zeta'_0 + \delta \xi_{mxt}}{\zeta_1} \ln y_{mt} + \varepsilon_{mxt}$

Eq 3 is estimated separately for each of the 835 coefficients, corresponding to the 851 "4-digit SITC plus" product categories in the dataset, using a two-stage least squares method. ξ_{mxt} is a component of p_{mxt} , so the regressor $(\ln p_{mxt} \ln y_{mt})$, is correlated with

the error term (ξ'_{mxt}). Therefore, $\ln p_{mxt-1} \ln y_{mt}$ is used as an instrument for $\ln p_{mxt} \ln y_{mt}$. The regression coefficients are then used to make extensive quality estimates that is adjusted for production costs and selection bias:

$$\text{Quality estimate}_{mxt} = \delta \ln \theta_{mxt} = \zeta'_1 \ln p_{mxt} + \zeta'_2 \ln y_{xt} + \zeta'_3 \ln \text{Dist}_{mx} \quad (4)$$

Countries that export high-quality products are not only realize high profit margins but also create more significant employment opportunities. Thereby elevating overall welfare levels. The international demand for high-quality goods correlates with increased export volumes, which in turn stimulates a higher flow of foreign currency. This flow is instrumental in augmenting national income and per cap-

ita income. Also, it is important in fostering an environment conducive to savings and investment, and further rising economic growth. In the high-quality product gains, corporations are usually impreviently obtain innovative technologies along with multicomplex production methods to simultaneously enhancing productiveness and minimizing costs. Hence, while the amplification of gain margins hap-

pens, businesses can raise the capacity of production and this provokes extra employment. Besides, centering quality behoves increase in R&D investments. Consequently, promoting techs and output innovations strengthen global competitiveness while creating new avenues in worldwide economies. Such dynamism do not only escalates quantities of export or earnings of foreign exchange. It intensifies respect and prestige of the state globally. Having such a statu can cause a rise in demand for products produced in the country along with amplification of brand value, premium pricing and profit enhancement. Nevertheless, it should better be adressed that product quality enhancement ordinarily relies on improving production procedures, output design and sourcing higher-quality raw material, which have the potential to elevate operating costs. If the costs increases, these expenses can unwittingly lessen competitiveness of traders, when synchronously can decrease profits. Likewise, if improvements in quality steers escalation of prices, then exporters can be at risk to meet reduction in rivalry and thereby detrimentation of trade share and retardmentation in growth trajectories. Besides, high-quality products often cater to specific market segments, that may create product diversity depreciation and raise of reliance on a singular market. Therefore, fluctuations in the needs of the markets or magnified rivalry can adversely influence export-dealers, emphasizing the complexities in pursuit of quality.

The persuasion of export quality on growth provisional to many elements as a country's level of development, attribution of export merchandises or globally predominant trade atmosphere.

Corporations which deals with high-quality commonly experience augmentation in production sizes determined via lifted profit ranges. But, mentioned expansion may lead to unexpected raise

in both energy and water consumptions as well as increase in waste generation so environmental pollution. To alleviate the cost of manufacturing, some corporations may opt to relocate their businesses to countries which have looser ecological rules and regulations. This alleviation, on the other hand, may worsen these jurisdictions' pollution problems. However, the high-quality exporter firms oftenly invest in highly viable techs that uprises efficiency of allocation of resources thereby may lessen the pollution. Additionally, corporations must abide multinational environmental regulations in order to avoid punishment and hence maintaining their positions in competitive market arena. Eventually, the complex interaction between EQ and environmental outcomes highlights to have integrated approaches via emphasizing economic advancement and ecological preservation. Securing this conciliation is important to achieve sustainable development in an increasingly interconnected world.

2.1. Empirical Literature Review

Although the effect of exports on economic growth is extensively discussed in the literature, the link interjacent of quality and production-related carbon emissions has gathered higher attention only in past two decades. Therefore, in this part the aim is to elucidate the aforementioned knotty link among export quality (EQ), economic growth (G), and carbon emissions (CE) through examining the applied literature. This functional literature mostly designed by econometric model analysis such as panel data and/or time series. Thereupon, the main aim is to synthesize only econometric-based research and try to explain the interation between critical parameters.

Table 1 exhibits econometric-based reseach that investigates trilateral relationship.

Table 1. Selected Empirical Literature

	Authors	Sample (Period)	Method	Findings
Export Quality & Economic Growth Nexus	Kiiza et al. (2022)	United States, Sub-Saharan African Countries (1963-2010)	GMM	Rise in EQ increases income convergence.
	Bilgili et al. (2022)	United States (1980-2019)	Markov Switching Model	A positive impact of EQ on G
	Wang et al. (2021)	Austria, Norway, Finland, Ireland, Japan, Singapore, Sweden, South Korea, US, Switzerland, UK, Brazil, Canada, China, India, Italy (1980-2014)	Panel Cointegration FMOLS, DOLS, Granger Causality Test	Higher EQ generally reduces CE
	Henn et al. (2013)	178 countries (1962-2010)	Panel Data Analysis, GMM	EQ increases G in developing countries
	Jarreau & Poncet (2012)	China (1997-2009)	Regression Analysis	Positive impact of EQ on G

Unpacking Türkiye's Trilateral Trade-Off: Export Quality, Growth, and Carbon Emissions

Export Quality and Carbon Emissions Relationship	Manova & Zhang (2012)	China (2003-2005)	Regression Analysis	Higher the quality goods leads higher quality inputs
	Bustos (2011)	Argentina (1992-1996)	Generalized Differences-In-Differences Estimation Method	EQ rises G
	Hausmann et al. (2006)	United States (1992-2003)	Fixed Effect, Random Effect, Regression Analysis	Increase in EQ rises G
	Manga et al. (2023)	China, Thailand, Philippines, Indonesia, South Korea, India, Oman (1970-2014)	ARDL Bounds Testing	Higher EQ reduces CE in China and India, but increases in Thailand and the Philippines.
	Trinh et al. (2022)	29 countries and regions in East Asia and the Pacific (1975-2014)	FMOLS, DOLS, Granger Causality Test	1% increase in EQI leads a 0.071% increase in CE.
	Wang et al. (2021)	Austria, Norway, Finland, Ireland, Japan, Singapore, Sweden, South Korea, US, Switzerland, UK, Brazil, Canada, China, India, Italy (1980-2014)	Panel Cointegration, FMOLS, DOLS, Granger Causality Test	Higher EQ reduces CE
	Doğan et al. (2020)	63 Developed and Developing Countries (1971-2014)	Pooled OLS, Panel Quantile Regression Model	Increase in EQ reduces environmental degradation in high-income countries, but less reduction in low-income countries.
	Murshed & Dao (2020)	Selected South Asian Economies (1972-2014)	Gregory-Hansen Cointegration Test, FMOLS, Mean Group, and Common Correlated Effects Mean Group Estimator	Increase in EQ reduces CE
	Fang et al. (2019)	82 Developing Countries (1970-2014)	Fixed Effects Model	Increase in EQ has a positive impact on the rate of increase in CE
	Gozgor & Can (2017)	China (1971-2010)	ARDL Bounds Test, Error Correction Model, Granger Causality Test	Increase in EQ decreases CE
	Nguyen & Su (2022)	30 low and lower-middle-income, 21 upper-middle-income, and 41 high-income economies (2002-2014)	Pooled OLS Method	EQ reduces income inequality.
	Wang et al. (2021)	Austria, Norway, Finland, Ireland, Japan, Singapore, Sweden, South Korea, US, Switzerland, UK, Brazil, Canada, China, India, Italy (1980-2014)	Panel Cointegration, FMOLS, DOLS, Granger Causality Test	G and urbanization rise CE
	Nguyen & Su (2021)	49 Low and Lower-Middle-Income, 31 Upper-Middle-Income, and 48 High-Income Economies (2002-2014)	Fixed Effect, Random Effect, Dynamic Panel Data Model	Significant bidirectional causality between financial development indicators and export quality.

Carbon Emissions and Economic Growth Relationship	Murshed & Dao (2020)	Selected South Asian Economies (1972-2014)	Gregory-Hansen Cointegration Test, FMOLS, Mean Group, CCE Mean Group Estimator	The panel data analysis results support the Environmental Kuznets Curve (EKC) hypothesis, but country-specific results show heterogeneity in this regard.
	Fang et al. (2019)	82 Developing Countries (1970-2014)	Fixed Effects Model	Increase in G increases CE
	Adu & Denkyirah (2018)	7 West African countries (1970-2013)	Fixed Effects, Random Effects	G significantly increases CE in the short term and not significantly reduce degradation in the long term.
	Omri (2013)	14 MENA Countries	GMM	Bidirectional causality relationship between G and CE

The possible acquired knowledge from Table 1 can be outlines as follows:

- Export quality directly link and mostly assists growth (Kiiza et al., 2022; Bilgili et al, 2022; Henn et al., 2013).
- An increase in export quality can reduce income convergence and environmental degradation (Doğan et al., 2020).
- Firms using higher quality inputs and producing higher quality goods are more successful (Manova & Zhang, 2012).
- The diversity and quality of the export portfolio can have a significant impact on economic growth (Hausmann et al., 2006).
- An increase in export quality reduces carbon emissions (Wang et al., 2021; Doğan et al. 2020; Murshed & Dao, 2020).
- There are mixed impressions regarding whether export quality leads or not to leads a rise in carbon emissions (Manga et al., 2023; Trinh et al, 2022; Fang et al. 2019).
- Economic growth increases carbon emissions (Wang et al., 2021; Murshed & Dao, 2020; Fang et al. 2019; Adu & Denkyirah, 2018).
- Economic growth increases carbon emissions up to a certain point but reduces them at higher income levels (Nguyen & Su, 2020).

As it can be detaily seen from Table 1 that the literature consistently insinuate high EQ-high EG-less CE triality. However, it is essential to note that due to sophisticated dynamics of this triality may differ through time, sector and country.

2.2. Data and Methodology

This study investigates the causal Nexus among EQ, G and CE in Türkiye. Due to data constraints, it was necessary for the analysis to cover from 1963 to 2023, and the selection of variables was guided by existing literature. EQI stands for export quality, with data sourced from the IMF database. Economic growth is represented by GDP (in constant 2015 USD) per capita, while carbon emissions are represented by Carbon Emissions (CRB) per capita. Both data sets obtained from the World Bank. The GDP variable is log-transformed. EQI and CRB variables are analyzed in their original forms, as they are expressed in ratios and indices.

For this study, the following methodology is employed:

1. Descriptive statistics of the variables are analyzed.
2. A unit root test is applied to determine the stationarity degree of the variables. In this study, the Fourier Augmented Dickey Fuller (FADF) unit root test is used.
3. Since stationarity is detected, FTY casuality test is deemed appropriate for the study.
4. The triality is also examined using Wavelet analysis, since because it produces time-frequency decomposition as well as has superiority in time-frequency localizations.

The FADF unit root test is traditional Augmented Dickey Fuller (ADF) test's prolongation, diffent along with Fourier expressions in formulated test equation. The mentioned test occupies nonlinear demeanors as well as structural breaks of series in a superior way through employing Fourier series. Such aspect is exceptionally beneficial to notice nonlinear Dynamics and structural amendments oftenly inspected in both economical and financial time series. Enders and Lee (2012)'s central equation is below:

$$\Delta y_t = \alpha_1 + \delta_t + \beta y_{t-1} + y_1 \sin\left(\frac{2\pi kt}{T}\right) + y_2 \cos\left(\frac{2\pi kt}{T}\right) + \sum_{i=1}^p \theta_i \Delta y_{t-i} + u_t \quad (5)$$

In Eq 5, y_t denotes for the time series, t shows the trend, π signifies the constant pi, T means the data's total size. Again, in the equation, k represents the frequency that minimizes the sum of squared residuals when the parameters sign as $\alpha, \delta, \theta, y_1, y_2$. The equation's error term is u_t . The abovementioned test finer in terms of capturing nonlinear structures and structural breaks, enabling more precise simulation of the sophisticated dynamics for the time series used in this study.

Thereafter assessing the variable stationary, the FT-Ycasuality test has employed in order to examine whether a causality exist or not. This assay purposes to figure nonlinearity in structures and structural breaks in used series via annexing Fourier term into Toda-Yamamoto (TY) model in order to check finer accuracy and reliability of the results. Through the test, firstly each time series' the degree of integration (d) has been determined. Later, the model has

predicted by employing aforesaid determined lag length (p) together with Fourier terms. Also, Wald tests have carried out via both the calculated integration degrees and " p "s. Hereunder mentioned tests monitor whether the coefficients are zero. In case where the Wald test implies the coefficient values are different from zero, causality can be said. According to Alper et al (2022) and Singh (2023) the test has a greater ability to capture non-linear structures and structural breaks; and it can be utilized albeit the used series have diverse degree of integration.

The Fourier methodology can be used to examine structural alterations of anonymous timing, frequency and form. So the test literaturally accepted as fairly plain technique- which examines gradual changes under the lack of anterior knowledge on either date, number and nature of breaks- to capture long-term movements and swift breaks as reported by Nazlioglu et al (2018) reported as

$$y_t = a(t) + \beta_1 y_{t-1} + \dots + \beta_{p+d} y_{t-(p+d)} + \varepsilon_t \quad (6)$$

The structural changes stated as $a(t)$ which is also a function of time is shown at Eq 6 (Becker et al. 2006).

$$a(t) = \alpha_0 + \sum_{k=1}^n y_{1k} \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^n y_{2k} \cos\left(\frac{2\pi kt}{T}\right) \quad (7)$$

In Eq 7 k , a particular frequency, y_1 measures the amplitude of the frequency, and y_2 measures the phase shift of the frequency. A high (n) value can cause fluctuations in stochastic parameters, limiting degrees of freedom, and increasing the risk of overfitting. However, a single Fourier frequency can model different breaks in deterministic components regardless of the time, number, or form of the break.

Increasing the n value causes changes in stochastic parameters, reducing degrees of freedom and leading to overfitting. A single Fourier frequency can mimic different breaks in deterministic components, regardless of the timing, number, and form of the break (Becker et al. 2006). Based on this information, $\alpha(t)$ can be defined as follows using a single frequency component (Nazlioglu et al., 2016): By consider-

$$a(t) = \alpha_0 + y_1 \sin\left(\frac{2\pi kt}{T}\right) + y_2 \cos\left(\frac{2\pi kt}{T}\right) \quad (8)$$

ring Eq 8 and Eq 6 together, the following equality can be obtained:

$$y_t = \alpha_0 + y_1 \sin\left(\frac{2\pi kt}{T}\right) + y_2 \cos\left(\frac{2\pi kt}{T}\right) + \beta_1 y_{t-1} + \dots + \beta_{p+d} y_{t-(p+d)} + \varepsilon_t \quad (9)$$

The statement of "*there is no causality*" is scrutinized by Wald test. This Wald statistic has asymptotical chi-square (χ^2) distribution and p degrees of freedom. The way to reject the null hypothesis is that this statistical figure exceeds the critical value, which in this case indicates a casual relationship. In vice versa, the null hypothesis stands, suggesting that no casual relationship exists (Nazlioglu et al., 2016).

The functioning doctrine of Wavelet analysis test derives from inspecting signals at divergent frequencies. In other word, in each frequency it is possible to capture wave-like actions (Cazelles et al., 2006). Since the Wavelet is a vigorous test which permits

signals and fuctions in various scales, the possible relationship examined by wavelet analysis as well. According to Mallat (2009), since this test prevails some traditional techniques such as Fourier analysis' limitations and allows time-frequency decomposition like surpassing in localization, it let to examine time parameters of signal and frequency component of this signal at the same time. Hence Wavelet technique is a multipurpose test to analyze both short-run circumstances and high-frequency factors. Moreover, it helps superfluous factors like noise or seasonality; thereby creates better distinctive results.

Furthermore, Continuous Wavelet Transform (CWT) model is a practice which use particularized function set (wavelet) to decompose an indicator in the time-frequency plane. The wavelet can be defined via two pivotal properties: it is limited by time and frequency and the mean of it have to be zero (Holschneider, 1995). Meaning that the wavelets port-

raying signals' various scale components, evaluate different range of frequencies and time-periods. But, it can be possible under the condition of shifting the waves along with diversifying scale and time positions. The primary wavelets ($\psi(t)$) involves time position (shift-in-time) (τ) along with frequency (expansion) (f) functions (Cazelles et al, 2008):

$$\psi_{f,\tau}(t) = \frac{1}{\sqrt{f}} \psi\left(\frac{t-\tau}{f}\right) \quad (10)$$

The introduced parameters regulate the location and the extent of the signal's wave. On the basis of the selected primary wavelet, time series' wavelet transform $[x(t)]$ can be carried out as this: When the $[x(t)]$ signal multiplies by a certain primary wavelet, this composed wavelet can be implemented at several positions and scales. After obtaining the coefficients, signal's time-frequency can be reached

through and for every differentiated scale and time, the characteristics of the signal can be revealed. Hence the wavelet transform of the time series $x(t)$ with a selected primary wavelet can be performed. Mentioned transformation covers $x(t)$ signal times a particular primary wavelet and utilization of the resulted wavelet in different scale and time (Cohen, 2003; Liang, 2004):

$$W_x(f, \tau) = \frac{1}{\sqrt{f}} \int_{-\infty}^{+\infty} x(t) \psi^*\left(\frac{t-\tau}{f}\right) dt = \int_{-\infty}^{+\infty} x(t) \psi_{f,\tau}^*(t) dt \quad (11)$$

The acquired coefficients point the signal through the time-frequency range. The "*" demonstrates some sort of complex conjugation which is crucial to examine signals and wavelets. By using "*", it can be probable to purify wavelets, to figure zero intersections and to get phase details. Cazelles et al (2008) describes this transformation as cross-correlation of signal and wavelet at different time (τ) and frequency (s). In other word, it implies finding signals via matching them with wavelets. When the normali-

zation of $1/\sqrt{f}$ equalizes wavelet to unit, each positions through time become comparable (Tiwari & Albulescu, 2016). By sustaining the identical energy in each scale, the wavelets can provide consistent outcomes for different time-positions. This method assists to perceive mutual time series' characteristics at various frequencies and how they modifies in time (Torrence & Webster, 1999). Therefore, for this paper, the link among the variables has probed employing wavelet coherence technique:

$$R_n^2(s) = \frac{\left| S\left(s^{-1} \psi_n^{(f,\tau)}(s)\right) \right|^2}{S\left(s^{-1} \left| \psi_n^f \right|^2\right) \cdot S\left(s^{-1} \left| \psi_n^\tau \right|^2\right)} \quad (12)$$

s utilizes to coefficient smoothing which are acquired through the transformation. This procedure enables to observe more conventional trends along with less fluctuated data. Additionally, $R_n^2(s)$ has an essential role in equation. The $R_n^2(s)$ can

be stated as "square wavelet coherence coefficient-SWCC" measures correlation power of time series. This coefficient ranges from 0 to 1, with a value close to 0 indicating weak or no relationship between the two time series, while

$$S_\tau(W) = \left(W_n(s) * \lambda_1^{-t^2/2s^2} \right); S_f(W) = \left(W_n(s) * \lambda_2 \Pi((0,6s)) \right) \lambda_1 + \lambda_2 \quad (13)$$

λ_1 and λ_2 are both normalization constants when Π stands for a rectangular function. In this equation Torrence & Compo (1998) settled 0.6 figure as an empirically determined averaging instrument.

3. Findings and Discussion

EQI, GDP and CRB correlation results based on unit root test are presented at Table 2. Based on the findings, when the test stats of EQI and CRB variables are modelled via constant values, these series reveal non-stationary. Also, test stat for GDP declines under the critical value and shows stationarity at 10%

level of significance. Moreover, the findings of both constant and trend models indicate non-stationarity of EQI and CRB series when GDP still reveals significance at 5%.

According to EQI-GDP-CRB first difference analysis, stationarity exist for each of them at 1% significance threshold for both constant and trend models. Yet, since the variables' test stats fall beneath critical level at 1%, it is highly possible that EQI and CRB become stationary once differenced. On the other hand, GDP shows powerful stationarity for each calculated situation.

Unpacking Türkiye's Trilateral Trade-Off: Export Quality, Growth, and Carbon Emissions

Consequently, for modeling and forecasting purposes, the GDP series can be considered more reliable, whereas the EQI and CRB series should be analyzed

using their differenced data, as they only achieve stationarity in their first differences.

Table 2. FADF Test Findings

Level				First Difference		
Constant Model						
Variables	Test Statistic	Fourier number	Lag length	Test Statistic	Fourier number	Lag length
EQI	-2.3879	4	1	-5.4228***	1	1
GDP	-3.6666*	1	1	-11.6777***	5	0
CRB	-2.3591	4	3	-6.3103***	5	1
Constant+Trend Model						
EQI	-2.8342	3	1	-5.4493***	1	1
GDP	-4.0823**	3	4	-11.6784***	5	0
CRB	-3.0621	1	3	-6.3151**	1	1

Note: The symbols *** and ** in the Table represent stationarity at the 10%, 5%, and 1% significance levels, respectively. Critical table values acquired from Enders and Lee (2012).

Table 3 provides the evidence from the causality examination conducted among the EQI, GDP, and CRB. Accordingly, both asymptotic and bootstrap p-values indicate:

- No causality effect of EQI on GDP.
- No causality effect of GDP on EQI.
- No causality effect of EQI on CRB.
- No causality effect of CRB on EQI.
- The asymptotic p-value is significant at the 0.10

level. And the bootstrap p-value is significant at the 0.10 level. They are indicating a causality effect of CRB on GDP.

- The asymptotic p-value is significant at the 5% level. Also the bootstrap p-value is significant at the 0.10 level. They are indicating a causality effect of GDP on CRB.

These findings indicate that there is no causal relationship between EQI, GDP and CRB, although a bidirectional causality exists between GDP and CRB.

Table 3. Fourier Toda-Yamamoto (FTY) Causality Test Findings

	Wald	Asym. p-val	Bootst. p-val	Lag	Frequency	Causality Relationship
H0: EQI ↔ GDP	0.447	0.88	0.80	2	3	EQI → GDP
	0.149	0.92	0.92	2	3	GDP → EQI
H0: EQI ↔ CRB	1.356	0.85	0.59	4	3	EQI → CRB
	0.760	0.94	0.77	4	3	CRB → EQI
H0: GDP ↔ CRB	8.735	0.06*	0.09*	4	2	CRB → GDP
	9.401	0.05**	0.08*	4	2	GDP → CRB

Note: The symbols *** and ** in the table represent statistical significance at the 10%, 5%, and 1% levels, respectively. Bootstrap p-values are based on 1000 repetitions

Figures 1, 2, and 3 illustrate the wavelet coherence findings examining the relationships between the EQI, GDP, and CRB variables. The accompanying color scale on the right indicates the strength of the correlation, with red and orange areas denoting high

(i.e., strong) correlation, and blue and green areas indicating low (i.e., weak) correlation. The color gradient ranges from 0 (blue) to 1 (red), reflecting the spectrum of correlation levels from weak to strong.

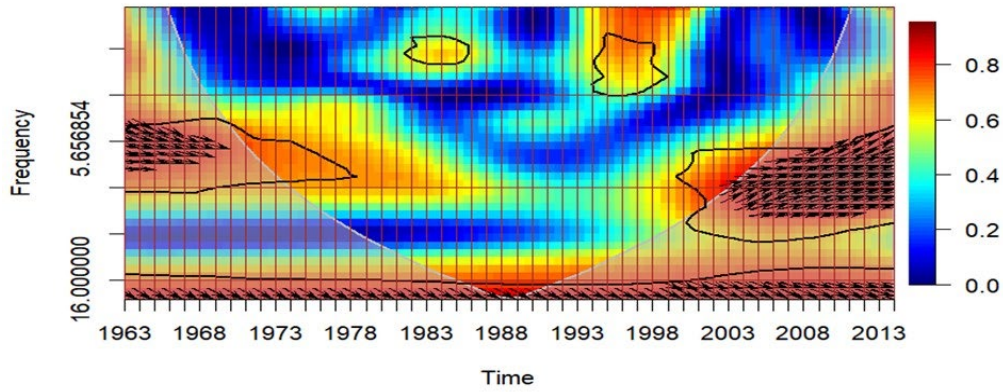


Figure 1. Wavelet Analysis Findings: EQI and GDP

Figure 1 illustrates the progressive link in between EQI and GDP over time, highlighting periods of varying strength in their correlation. Specifically:

- From 1963 to 1980, there is a favorable linkage observed between EQI and GDP. Both of the series moving in tandem, although EQI slightly precedes GDP.
- In the 1980s and 1990s, the relationship between EQI and GDP weakens significantly.
- From 2000 to 2013, a positive correlation re-emerges between EQI and GDP, with both series again moving simultaneously.

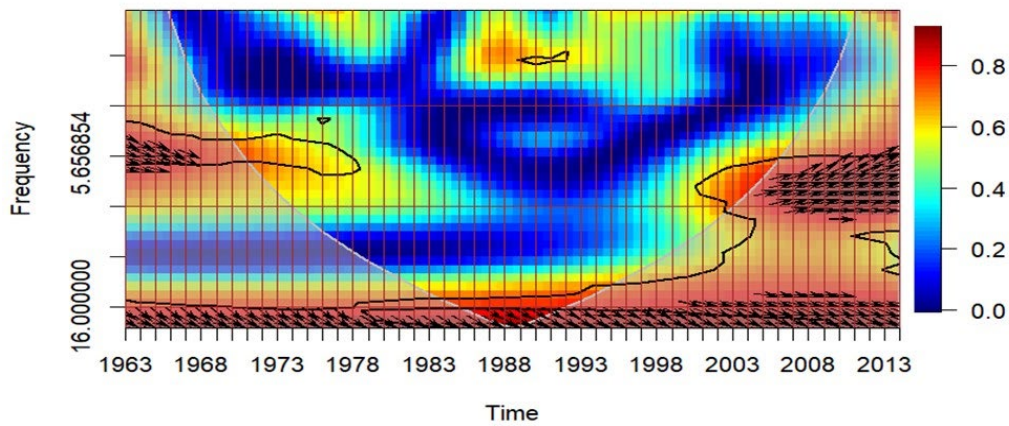


Figure 2. Wavelet Analysis Findings: EQI and CRB

From Figure 1 and 2, overall, a positive correlation between EQI and GDP is observed between 1968-1980 and 2000-2008, with both series moving in the same direction. In contrast, a weaker correlation is

noted in 80s and 90s. These findings from the wavelet coherence analysis (WCA) are partially consistent with the results obtained from the FTY test.

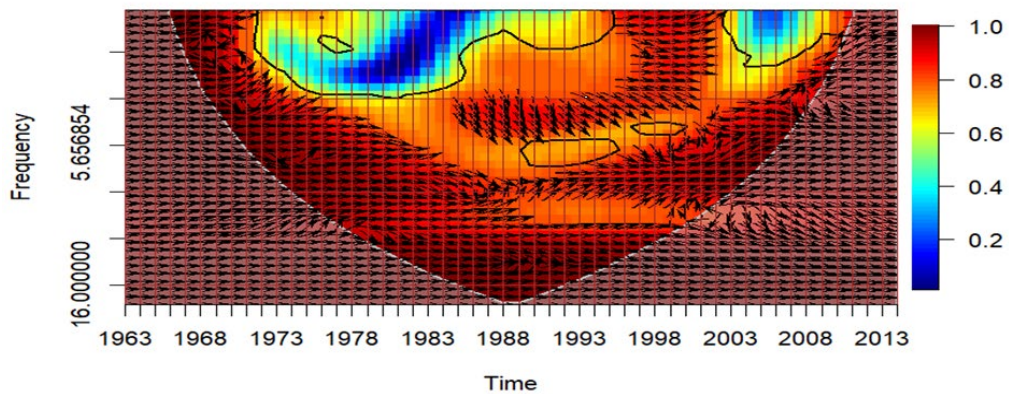


Figure 3. Wavelet Analysis Findings: GDP and CRB

Figure 3 presents the WCA results. The red areas on the graph signify a strong correlation when they are consistent with the findings of FTY test.

Overall, the findings indicate that these relationships are subject to temporal variations and may strengthen during specific periods. Wavelet Analysis reveals an upward linkage between EQ and national income during the periods 1963-1980 and 2000-2013, suggesting that improvements in Türkiye's EQ positively contribute to G. However, the analysis also identifies a weaker relationship between these variables during the 1980s and 1990s. Besides, there is not any direct causality in the midst of EQI and GDP according to FTY test. This indicates that for a certain time period EQ has favorable affect on growth but create neither consistent nor protracted relationship. The findings partly oppose the strong causality mentioned in some existing literature (i.e. Kiiza et al., 2022; Bilgili et al., 2022; Henn et al., 2013; Bustos, 2011; Hausmann et al, 2006). Also, the outcomes imply that EQ solely cannot be a direct driver of G. So, it is significant supplementary remediations in EQ along with rise in educational, technological and infrastructural investments overall in order to have a sustainable economic development.

Wavelet analysis findings also displays that there is a positive association within EQ and KE in 1963-1970 as well as 2000-2013. It means that when Türkiye's export quality rises via high carbon emissions which stresses the need of integrating environmental sustainability schemes with exertion of boost EQ. These results are parallel to Trinh et al (2022) and Manga et al (2023) findings. However, the findings contrariwise to Wang et al. (2021), Fanga et al. (2019) and Gozgor&Can (2017) findings since they claim the more reduction in CE creates betterment in EQ. Furthermore, this analysis suggests a weak correlation between EQ and CE for 1968 and 2000 period. The FTY analyze reports substantiate the causality absence in between EQ and CE.

In addition, Wavelet and FTY tests indicate bidirectional causality relationship of national income and CE. Such finding insinuates direct influence of G over CE when contrarily CE directly effect G. Here this "tendency of growth is likely to expand CE" finding is similar with Omri (2013), Nguyen& Su (2022), Wang et al.(2021) and Adu& Denkyirah (2018).

4. Conclusion

Endeavor of long-term development of emerging economies lie in effective structural transformation policies focused on amplifying productivity, radiating economic efforts as well as securing sustainable growth. In this regard, export quality has a pivotal function, assisting as an indicator of state's manufacturing refinements and its status into global value stream. Enhancing quality of export can return es-

sential economic advantages, comprising improved profit margins for cooperations, employment creation together with comprehensive welfare advancements. Augmented global demand for high-quality products not only amplifies intensity of export, but also lures pecunial foreign exchange gainings, exalting both national and per capita income. Such a created atmosphere fosters circumstances lead increases in savings and investment, while driving higher economic growth. Nonetheless, generating superior export quality requires embracing advanced technologies and manufacturing techniques, usually necessitating substantial investments in R&D. While the technical improvements can steer to inventions, ameliorate rivalry and decrease the costs of manufacturing, these improvements can also mean greater energy consumption and emission rates. Also, completely newly designed high-quality manufacturing may unwittingly increase generation of waste and may exacerbate environmental degradation. Moreover, in order to preserve international rivalry, companies must conform both national and multinational ecological regulations formed to monitor and alleviate degradation. Hence awareness of the sophisticate engagements amongst export quality, growth and environmental issues is significantly important for progressing holistic policies which balance economic development along with environmental liabilities. Therefore, this research examines the dynamic corelation amongst export quality, economic growth and carbon emissions, concentrating on Türkiye's experiences in 1963-2023 period. The study scrutinizes direct casual correlation and evolvement procedure of this relationship by utilizing Fourier Toda-Yamamoto causality and continuous wavelet analysis methods.

The findings reveal trilateral relationship alters across time and can be strengthen within certain terms. Particularly, an auspicious correlation between export quality and national income has been observed for 1963-1980 and 2000-2013. Yet, weakened ties have been observed during 80s and 90s. The lack of a direct casual link between the Export Quality Index and Gross Domestic Product indicates that while export quality positively affects economic growth during certain periods, it does not actually establish a consistent and long-term casual relationship as expected. Furthermore, the positive quality-emission relationship in 1963-70 and 2000-13 demonstrated that neither efforts to improve export quality nor environmental sustainability strategies can be addressed in isolation. Therefore, the importance of integrated efforts for Türkiye has become evident. Additionally, both wavelet and FTY analyses have demonstrated a bidirectional, mutually reinforcing relationship between national income and emissions. The results also show that export quality alone is not a direct driver of sustainable economic growth. For sustainable development, improve-

ments in export quality must be supported by investments in education, technology, and infrastructure. Moreover, the strong relationship between national income and carbon emissions highlights the need to incorporate environmental sustainability into economic growth policies. In this regard, investments in renewable energy, energy efficiency, and sustainable development goals are crucial.

In order to achieve sustainable development goals, Türkiye must integrate environmental sustainability into its economic growth policies. Considering the affirmative export quality-carbon emissions relation, as well as the bidirectional and mutually reinforcing relationship between carbon emissions and economic growth, the findings suggest that export quality is the key determinant of a country's competitiveness, sustainability, and innovation in international markets. Export quality encompasses both the value-added and technological content of products. In light of this, valuable insights can be drawn from the practices of countries such as Germany, the Netherlands, and South Korea, and applied to Turkey. Products produced using renewable energy could be enhanced with international certifications such as the Carbon Trust, creating higher value-added products that can be sold at premium prices. In this context, Turkey could adopt Germany's "Energiewende" policy, reducing dependency on solid waste while simultaneously increasing the competitiveness of export products produced with renewable energy in international markets. In reality Türkiye is in a highly advantageous position, with considerable potential to leverage renewable resources such as wind, solar, and hydroelectric power. Similar to Germany's approach, the Turkish government should support renewable energy projects through incentives and subsidies. For example, Germany's "Feed-in Tariff" (FiT) model, which guarantees renewable energy producers the ability to sell energy at a fixed price for a designated period, has proven effective in fostering investment in the sector. Türkiye could adopt a similar strategy by providing long-term guaranteed pricing, thus encouraging private sector investment in renewable energy projects. A phased reduction in fossil fuel dependence could be pursued, but this transition must be carefully considered due to Türkiye's reliance on coal and natural gas. To mitigate the social and economic consequences of this shift, workforce retraining and transformation programs should be implemented. Türkiye's youthful population offers a unique opportunity to create jobs in advanced sectors such as renewable energy technologies. However, Türkiye's current energy infrastructure is inadequate to support the increased integration of renewable energy, requiring substantial financial resources for new infrastructure investments and grid enhancements. Although low-interest loans or grants can be obtained from transnational entities such as the World Bank and

the European Bank for Reconstruction and Development (EBRD), an effective approach would be to channel these funds through public-private partnerships, supplemented by government-backed incentives. Moreover, instead of relying solely on conventional methods, issuing green bonds could establish a cost-reducing, profit-generating incentive mechanism within the domestic market, simultaneously opening the Turkish market to foreign investors under well-structured, robust legal frameworks.

In addition, Türkiye could draw inspiration from the Netherlands' organic farming and smart agriculture practices for environmentally friendly industrial production. Given the current production processes and firm preferences in Türkiye, the rapid adoption of green chemistry, clean production techniques, or biological pesticides in place of conventional ones—as seen in the Netherlands—may not be immediately feasible. Nevertheless, the integration of digitalization and industrial simulation techniques, such as sensors and smart production systems, could aid in reducing the use of chemicals in production processes. The success of waste recycling initiatives in Türkiye's automotive sector, particularly in the context of green production and waste management, can serve as a model for larger-scale waste minimization strategies. The Ministry of Environment, Urbanization, and Climate Change could expand its "Zero Waste" initiative into a more substantial government-supported waste management grant program. Municipalities, alongside the Ministry of Environment, could provide financial assistance for establishing recycling systems, while offering tax incentives for those participating in the initiative and imposing penalties on non-compliant entities. Furthermore, central and local governments could implement green city models inspired by Copenhagen, which would not only increase green spaces, parks, and eco-friendly living areas but also introduce smart water grid solutions. These systems would enable real-time monitoring of water consumption and pressure, helping to identify leaks and losses quickly, thereby enabling effective intervention and generating industrial outcomes. Finally, increasing investments in education and technology could help foster an innovation ecosystem similar to South Korea's technological advancement. While this approach is both long-term and challenging, it remains the most realistic and sustainable path toward achieving enduring economic growth. Future research should aim to further explore these relationships in greater depth and provide data that can support more informed policymaking.

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