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Research Article

ECONOMIC GROWTH, RESOURCE EFFICIENCY, AND SUSTAINABLE BUSINESS STRATEGIES IN THE TURKIC REPUBLICS: EVIDENCE FROM MATERIAL FOOTPRINT COMPONENTS

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ABSTRACT

This study examines whether economic growth is associated with material pressure and resource efficiency in the Turkic Republics by focusing on disaggregated material footprint components (biomass, fossil fuels, metal ores, and non-metallic minerals) during the 1992–2024 period. Using second-generation panel econometric techniques that account for cross-sectional dependence, heterogeneity, and structural breaks, the study evaluates whether growth is associated with material decoupling in resource-intensive transition economies. The findings reveal no stable long-run cointegration relationship under regime shifts, suggesting that growth–resource dynamics are shaped mainly by cyclical and structural factors rather than sustained decoupling. The causality results identify a statistically significant unidirectional causal relationship running from economic growth to non-metallic mineral consumption, highlighting the role of construction – and infrastructure-related material demand. Overall, the results indicate limited evidence of sustained material decoupling and emphasize the need to complement emission-focused policies with material efficiency, circular economy practices, sustainable business strategies, green supply chains, and resource-efficient production.

Keywords: Material footprint, Economic growth, Resource efficiency, Sustainable business strategies, Circular economy.

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Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

INTRODUCTION

The rapid expansion of the global economy over the last five decades has increased prosperity while driving resource consumption beyond the regenerative capacity of natural systems. Conventional growth models based on intensive raw material use have contributed to major environmental challenges, including climate change and biodiversity loss, thereby placing increasing pressure on ecosystems (Wiedmann et al., 2015). As a result, decoupling economic growth from resource use has become a central objective within the framework of the United Nations Sustainable Development Goals, particularly SDGs 8 and 12.

Environmental degradation has traditionally been assessed using carbon emissions. However, emission-based indicators often fail to capture the environmental pressures embodied in international trade and global production networks, where developed economies may shift resource-intensive production to developing countries (Giljum et al., 2014; Wiedmann & Lenzen, 2018; Wiedmann et al., 2015). To address this limitation, the Material Footprint (MF) approach measures the total amount of raw materials extracted globally including biomass, fossil fuels, metal ores, and non-metallic minerals to satisfy final demand (Ulucak et al., 2020). By incorporating global supply-chain linkages, MF provides a broader assessment of the environmental pressure associated with production and consumption activities (Cialani et al., 2025; Wood et al., 2018). This broader perspective is also relevant to debates in business and management, since firms increasingly face pressure to reduce material intensity, improve resource efficiency, and align production and supply-chain decisions with sustainability-oriented market expectations.

The relationship between economic growth and material consumption is commonly discussed within the framework of the Material Kuznets Curve (MKC) and the decoupling hypothesis. The MKC suggests that material use may initially increase during the early stages of economic development but may later decline as economies undergo technological upgrading, structural transformation, and improvements in resource efficiency (Avcı, 2023). However, this study does not directly test the MKC as a strict inverted-U hypothesis, since the empirical specification does not include a quadratic income term or estimate a turning point. Rather, the MKC is used as a conceptual framework for discussing whether economic growth in the Turkic Republics is associated with sustained material decoupling or continued material pressure. Accordingly, the empirical focus of the study is on identifying the material-specific channels through which economic growth generates resource pressure.

The decoupling literature distinguishes between absolute decoupling, where environmental pressure declines despite economic growth, and relative decoupling, where resource use continues to increase but at a slower pace than income growth (Haberl et al., 2020; Pothen & Welsch, 2019; Schandl et al., 2018; Steinberger et al., 2013). However, empirical findings remain mixed. Although some studies report relative decoupling in OECD and G7 economies (Rahman et al., 2025), many emerging and transition economies continue to follow material-intensive growth patterns (Kassouri et al., 2021). In particular, carbon decoupling does not necessarily imply material decoupling, since infrastructure expansion, urbanization, and capital accumulation may continue to increase material demand despite improvements in energy efficiency and reductions in

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

carbon intensity (Krausmann et al., 2009; Regueiro-Ferreira & Alonso-Fernández, 2023). This issue is especially relevant in economies where growth strategies rely heavily on construction activity, large-scale infrastructure investment, and resource-intensive production systems.

Recent global evidence suggests that dematerialization has not yet emerged as a consistent global trend (Nagano et al., 2025). This has increased interest in circular economy models emphasizing resource efficiency, sustainable infrastructure planning, and material – efficient production systems. Within this context, the Turkic Republics – Türkiye, Azerbaijan, Kazakhstan, Kyrgyzstan, Turkmenistan, and Uzbekistan – provide an important case due to their infrastructure-led development strategies and dependence on natural resource extraction, as well as the post-Soviet transformation processes experienced by all of these countries except Türkiye. Since the dissolution of the Soviet Union, these economies have pursued growth models centered on transportation corridors, energy infrastructure, and mineral-intensive industrialization. As a result, demand for non-metallic minerals such as cement and construction aggregates has increased substantially, generating additional environmental pressure through land degradation, waste generation, and urban expansion. Compared with advanced economies, where technological upgrading may reduce material intensity, transition economies often experience growth phases characterized by infrastructure expansion and resource-intensive production. Moreover, the strategic role of the Turkic Republics within regional logistics and energy networks further underscores their relevance to sustainability debates.

Despite the growing literature on economic growth and environmental pressure, empirical evidence on the Turkic Republics remains limited. Existing studies often rely on aggregate indicators such as CO_2 emissions or total material footprint, potentially masking material-specific dynamics. In addition, many studies overlook structural breaks and cross-sectional dependence, both of which are common features of panel data on transition economies exposed to institutional changes and external shocks. Accordingly, this study investigates whether economic growth in the Turkic Republics is associated with increasing material pressure by focusing on disaggregated material footprint components. Specifically, the analysis examines biomass, fossil fuels, metal ores, and non-metallic minerals in order to identify the material-specific channels through which growth-oriented development patterns generate resource pressure. This framing is particularly relevant to the Turkic Republics, where infrastructure expansion, construction activity, logistics corridors, and resource-intensive industrialization have played an important role in their development processes, particularly in the post-Soviet transformation of the five former Soviet republics.

This study contributes to the literature in three main respects. First, unlike studies relying mainly on CO_2 emissions or aggregate material footprint indicators, it examines disaggregated material footprint components and therefore identifies which material category is most closely associated with economic growth. Second, it focuses on the Turkic Republics and employs second-generation panel econometric techniques that account for cross-sectional dependence, heterogeneity, and structural breaks, thereby providing methodologically robust evidence from a relatively underexplored group of emerging and transition economies. Third, by linking growth-induced material pressure to resource efficiency, circular economy practices, sustainable procurement, and green supply

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

chain management, the study connects macro-level resource dynamics with sustainable business strategies.

LITERATURE REVIEW

Recent studies increasingly argue that emission-based indicators are insufficient to capture the environmental pressures associated with resource-intensive growth, leading to growing interest in material footprint (MF) indicators as broader measures of environmental pressure (Wiedmann & Lenzen, 2018; Wiedmann et al., 2015). Unlike production-based indicators, the MF framework measures the total amount of raw materials – including biomass, fossil fuels, metal ores, and non-metallic minerals – extracted globally to satisfy final demand, (Ulucak et al., 2020; Wood et al., 2018). This consumption-based perspective is increasingly used to evaluate environmental sustainability and progress toward Targets 8.4 and 12.2 of the Sustainable Development Goals (SDGs) (Cialani et al., 2025; United Nations Environment Programme, 2024). By linking final demand, production structures, and global resource extraction, the MF approach also provides a useful basis for evaluating how firms, sectors, and supply chains contribute to resource pressure from a business sustainability perspective.

Empirical findings on material decoupling remain mixed. While some studies report relative decoupling in OECD and G7 economies (Karlilar & Pata, 2025; Rahman et al., 2025), evidence for absolute decoupling remains limited. Global assessments show that resource extraction continues to rise despite technological progress and efficiency gains (Haberl et al., 2020; Schandl et al., 2018). Similarly, Nagano et al. (2025), using data from 176 countries, conclude that material-intensive growth patterns remain dominant at the global level, with material footprints often exceeding sustainable thresholds (Zhang et al., 2017). These findings suggest that reductions in carbon intensity do not necessarily translate into lower material consumption. From a business perspective, this also implies that emission reduction strategies may remain incomplete unless they are accompanied by material efficiency, circular production practices, and resource-efficient supply-chain management.

The literature further indicates that these dynamics are particularly pronounced in emerging and transition economies. Following the transition to market-oriented systems, many Eurasian economies adopted development strategies centered on infrastructure expansion, transportation networks, and mineral-intensive industrialization (Giljum et al., 2014; Krausmann et al., 2009). In this context, the strategic role of regional logistics and energy corridors such as the “Middle Corridor” reinforces the material-intensive nature of growth in the region (Diriöz, 2022; Sönmez, 2021). Existing evidence also suggests that material consumption in such economies responds asymmetrically to economic cycles, increasing rapidly during expansion periods while declining more slowly during downturns (Abdi et al., 2025; Kassouri et al., 2021). Although improvements in resource productivity have been observed since the 1990s, transition economies continue to face greater sustainability challenges than advanced economies (OECD, 2024; Tekbaş, 2022). These challenges are not only macroeconomic or environmental in nature; they also affect business strategies, particularly in the infrastructure, construction, logistics, and industrial production sectors, which depend heavily on material-intensive inputs.

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

Recent studies have also examined the institutional and technological determinants of material footprints. Technological development and human capital formation may reduce resource intensity (Sahoo et al., 2021), whereas the transition toward renewable energy may increase demand for metal ores and non – metallic minerals required for green technologies (Regueiro-Ferreira & Alonso-Fernández, 2023). This highlights a potential tension between decarbonization and dematerialization, particularly in infrastructure-intensive economies (Shigetomi et al., 2016). Moreover, the effects of digital infrastructure and financial development on material footprints appear to vary across countries and stages of industrialization (Dada & Al-Faryan, 2024; Hou et al., 2024; Pothen & Welsch, 2019). In this regard, digitalization, financial development, and technological upgrading may influence not only national resource productivity but also firm-level decisions related to cleaner production, sustainable procurement, and the transition to circular business models.

Despite the growing literature, several gaps remain. First, many empirical studies continue to rely on CO_2 emissions or aggregate material footprint indicators, which may obscure material-specific dynamics. Second, the evidence on transition economies remains limited, particularly for the Turkic Republics, where post-Soviet restructuring, infrastructure-led development, and regional logistics projects create distinctive material demand patterns. Third, existing studies often overlook cross-sectional dependence, slope heterogeneity, and structural breaks, although these features are highly relevant for economies exposed to common shocks and institutional transformation. Finally, the link between macro-level material pressure and sustainable business strategies remains underexplored. This study addresses these gaps by examining disaggregated material footprint components in the Turkic Republics using second-generation panel econometric methods and by connecting growth-driven material demand to resource efficiency, circular economy-oriented business practices, sustainable supply chains, and green business transformation in resource-intensive transition economies.

DATA AND METHODOLOGY

This study examines the relationship between economic growth and material footprint components in the Turkic Republics – Azerbaijan, Kazakhstan, Kyrgyzstan, Türkiye, Turkmenistan, and Uzbekistan – over the 1992–2024 period. This timeframe captures the structural transformation of these economies from the post-Soviet transition era to the present, including their current roles within regional energy and logistics networks.

Material footprint indicators were obtained from the UNEP International Resource Panel (IRP) Global Material Flows Database (UNEP IRP, 2024), while real gross domestic product (GDP) data, measured in constant 2015 US dollars, were retrieved from the World Bank's World Development Indicators (WDI) (World Bank, 2025). Material footprint is preferred over conventional emission-based indicators because it captures the total volume of raw materials extracted globally to satisfy final demand. This consumption-based approach is particularly relevant for transition economies, where industrialization and infrastructure expansion remain major sources of environmental pressure.

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

Variable Selection and Specification

Drawing on the literature on decoupling and the Material Kuznets Curve, this study disaggregates the material footprint into four components to provide a more detailed assessment of growth-related material pressure: biomass-based material footprint (MFB), fossil fuel-based material footprint (MFF), metal ore-based material footprint (MFM), and non-metallic mineral-based material footprint (MFNM). This disaggregation reflects the distinct growth dynamics of the Turkic Republics, where infrastructure expansion and transportation investments particularly within the "Middle Corridor", framework, have increased demand for non-metallic minerals. Since the purpose of this study is not to directly test the inverted-U form of the MKC, the empirical model does not include a quadratic GDP term. Instead, the analysis focuses on whether economic growth is associated with material-specific resource pressure and whether such a relationship reflects stable decoupling or short – and medium-term growth-driven material dynamics. All variables are transformed using natural logarithms to reduce heteroscedasticity and allow the estimated coefficients to be interpreted as elasticities. Variable definitions and data sources are presented in Table 1.

Table 1
Variables Used in Analysis

Variable	Description	Unit / Conversion	Source
GDP	Real gross domestic product (constant 2015 US$)	logarithmic (ln)	World Bank (2025)
MFB	Biomass-based material footprint	logarithmic (ln)	UNEP IRP (2024)
MFF	Fossil fuel-related material footprint	logarithmic (ln)	UNEP IRP (2024)
MFM	Material footprint based on metal ores	logarithmic (ln)	UNEP IRP (2024)
MFNM	Footprint of non-metallic mineral-based materials	logarithmic (ln)	UNEP IRP (2024)

Source: Compiled by the authors based on World Bank (2025) and UNEP IRP (2024)

In line with the decoupling literature, this study treats economic growth as the main driver of material pressure rather than modeling material footprint components as determinants of GDP. Accordingly, the empirical specification is designed to examine whether increases in real GDP are associated with changes in disaggregated material footprint components. This structure is consistent with the main research objective of identifying the material-specific channels through which growth-oriented development patterns may intensify resource use in the Turkic Republics. The baseline material-specific model is specified as follows:

$$lnMF_{it}^{k} = \alpha_i + \beta_i \, lnGDP_{it} + \varepsilon_{it} \tag{1}$$

where $lnMF_{it}^{k}$ denotes the logarithm of material footprint component k for country i in year t. The superscript k refers to biomass-based material footprint

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

(*lnMFB*), fossil fuel-based material footprint (*lnMFB*), metal ore-based material footprint (*lnMFB*), and non-metallic mineral-based material footprint (*lnMFB*). $lnGDP_{it}$ represents real gross domestic product and is used as the indicator of economic growth. α_i captures country-specific effects, β_i denotes the country-specific response of material footprint components to economic growth, and ε_{it} is the error term.

Accordingly, the empirical analysis is conducted using four material-specific specifications, with *lnMFB*, *lnMFF*, *lnMFM*, and *lnMFNM* as the respective dependent variables. There specifications allow the analysis to identify whether economic growth generates uniform material pressure or whether the growth-driven effect is concentrated in specific material categories.

Table 2
Descriptive Statistics

	LNGDP	LNMFB	LNMFF	LNMFM	LNMFNM
Mean	24.575	17.521	16.325	15.461	17.174
Median	24.629	17.245	16.240	15.236	17.267
Maximum	27.893	19.564	19.303	18.680	20.885
Minimum	21.708	15.891	13.117	11.4042	12.575
Std. Dev.	1.602	1.033	1.646	1.962	1.843
Skewness	0.194	0.538	0.125	-0.015	-0.228
Kurtosis	2.201	2.107	2.175	1.985	2.965
Jarque-Bera	6.513	16.138	6.122	8.497	1.733
Probability	0.038	0.000	0.046	0.014	0.420
Sum	4865.881	3469.234	3232.435	3061.281	3400.644
Sum Sq. Dev.	506.204	210.277	534.110	758.343	669.679
Observations	198	198	198	198	198

Source: Compiled by the authors

The descriptive statistics reported in Table 2 indicate considerable differences in economic size across the countries in the panel, whereas the material footprint components display relatively stable distributions over time. Although the Jarque-Bera statistics suggest deviations from normality for some variables, the dataset remains suitable for parametric analysis.

As a preliminary step, cross-sectional dependence and parameter homogeneity were examined using the Breusch and Pagan (1980) LM test, the Pesaran (2004) CD test, and the LMAdj test proposed by Pesaran et al. (2008). The

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

findings reveal significant cross-sectional dependence for all variables, indicating that the countries are affected by common shocks and regional dynamics. In addition, the Pesaran and Yamagata (2008) homogeneity test indicates that the slope coefficients differ across countries, suggesting a heterogeneous panel structure. These results support the use of second-generation panel econometric techniques.

The stationarity properties of the variables were then evaluated using the CADF (Cross-sectionally Augmented Dickey-Fuller) panel unit root test developed by Pesaran (2007), which accounts for cross-sectional dependence. The results show that the variables are non-stationary in levels but become stationary after first differencing, indicating that all series are integrated of order one, I(1). Given the common order of integration, long-run relationships were investigated using the Westerlund and Edgerton (2008) panel cointegration test with structural breaks. While limited evidence of cointegration is found in models without breaks, the results indicate the absence of a stable long-run equilibrium relationship once structural breaks and regime shifts are incorporated. The estimated break dates largely coincide with periods of structural transformation in transition economies.

Since the long-run relationship appears weak and unstable, the analysis focuses on short – and medium-term dynamics. Accordingly, the direction of causality between economic growth and material footprint components are examined using the Emirmahmutoglu and Kose (2011) panel causality test, which accommodates panel heterogeneity and country-specific lag structures.

Empirical Strategy

The empirical strategy follows a sequential procedure consistent with the panel structure of the data. First, all variables are transformed into natural logarithmic form to reduce heteroscedasticity and allow the coefficients to be interpreted as elasticities. Second, cross-sectional dependence and slope heterogeneity are examined to determine whether first – or second-generation panel methods are appropriate. Third, the stationarity properties of the variables are tested using the CADF panel unit root test, which accounts for cross-sectional dependence. Fourth, the long-run association between economic growth and material footprint components is examined using the Westerlund and Edgerton (2008) panel cointegration test with structural breaks. Finally, since the cointegration results indicate weak and unstable long-run relationships, the direction of causality in the short and medium term is analyzed using the Emirmahmutoglu and Kose (2011) panel causality test.

FINDINGS

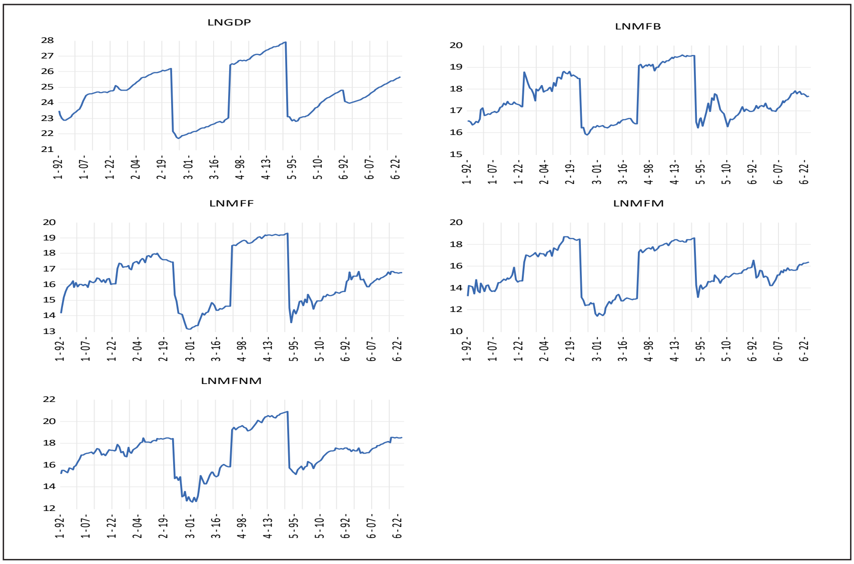
Before conducting the empirical analyses, time-series graphs were generated to examine the trends and structural characteristics of the economic growth and material footprint variables. Figure 1 presents the logarithmic series over the sample period. The graphs indicate that the variables exhibit both long-term trends and noticeable fluctuations during specific periods, suggesting the presence of common shocks and possible structural shifts across countries. These patterns suggest that conventional first-generation methods may be insufficient for assessing stationarity and long-run relationships. Accordingly, the subse-

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

quent analysis employs panel unit root and cointegration tests that account for cross-sectional dependence and structural breaks.

Figure 1

Time Path Plots of the Series



Note: All variables are in logarithmic form.

Source: Compiled by the authors

Preliminary visual inspection of the time – series graphs reveals similar directional movements across countries in both economic growth and material footprint components. The presence of common fluctuations and simultaneous disruptions suggests that the panel countries are influenced by shared shocks and regional dynamics. These observations highlight the need to test for cross-sectional dependence, an important consideration in panel data analysis. Accordingly, cross-sectional dependence was examined using the Breusch-Pagan LM test, the Pesaran CD test, and the adjusted LM (LMAdj) test proposed by Pesaran et al. (2008).

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

Table 3
Cross-Sectional Dependence Test Results

Constant	LNGDP		LNMFB		LNMFF		LNMFM		LNMFNM	
	Stats.	Prob.	Stats.	Prob.	Stats.	Prob.	Stats.	Prob.	Stats.	Prob.
***CD_{lm}* (BP,1980)**	23.495	0.074	54.186	0.000	30.364	0.011	48.778	0.000	32.222	0.006
***CD_{lm}* (Pesaran, 2004)**	1.551	0.060	7.154	0.000	2.805	0.003	6.167	0.000	3.144	0.001
***CD* (Pesaran, 2004)**	-3.247	0.001	-2.731	0.003	-3.781	0.000	-3.542	0.000	-3.788	0.000
***LM_{Adj}* (PUY, 2008)**	23.843	0.000	17.992	0.000	26.785	0.000	24.170	0.000	23.285	0.000

Note: ***, ** respectively indicate statistical significance at the 1% and 5% significance levels. $\Delta y_{i,t} = d_i + \delta_i y_{i,t-1} + \sum_{j=1}^{pi} \lambda_{i,j} \Delta y_{i,t-j} + u_{i,t}$ the number of lags is taken as 1.

Source: Compiled by the authors

The results reported in Table 3 indicate significant cross-sectional dependence for economic growth and all material footprint components. This suggests that the panel countries are influenced by common shocks, regional integration processes, and similar structural developments. Since first-generation panel methods may produce biased and inconsistent estimates in the presence of cross-sectional dependence, the findings support the use of second-generation panel econometric techniques that account for cross-country interactions. In addition, slope homogeneity across countries was examined using the Delta tests proposed by Pesaran and Yamagata (2008).

Table 4
Cross-Sectional Dependence and Slope Homogeneity Tests

	Test Stats.	p-value
***LM* (BP,1980)**	62.518***	0.000
***CD_{lm}* (Pesaran, 2004)**	8.676***	0.000
***CD* (Pesaran, 2004)**	3.866***	0.000
***LM_{Adj}* (PUY, 2008)**	13.427***	0.000
Homogeneity Test		
$\tilde{\Delta}$	12.992***	0.000
$\tilde{\Delta}_{Adj}$	13.831***	0.000

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. $\tilde{\Delta}$ and $\tilde{\Delta}$Adj denote the Delta and adjusted Delta slope homogeneity statistics, respectively.

Source: Compiled by the authors

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

The results presented in Table 4 show that both the Delta and adjusted Delta statistics are statistically significant, indicating that the slope coefficients are heterogeneous across countries. This finding suggests that the relationship between economic growth and material footprint components differs across the countries in the panel, reflecting variations in growth structures, resource endowments, and development trajectories. Combined with the evidence of cross-sectional dependence, these results support the use of second-generation panel econometric techniques. Accordingly, the stationarity properties of the variables were examined using the CADF panel unit root test developed by Pesaran (2007), which accounts for cross-sectional dependence.

Table 5
CADF Panel Unit Root Test

	Constant		**Constant and Trend**	
	Lags	CADF-stat	Lags	CADF-stat
lngdp				
Azerbaijan	1	-1.767	1	-2.520
Kazakhstan	3	-2.716	3	-2.654
Kyrgyzstan	1	-2.294	1	-3.887
Türkiye	1	-2.020	1	-2.465
Turkmenistan	1	-2.790	1	-2.284
Uzbekistan	1	-2.738	1	-1.369
Panel		-2.388		-2.530
lnmfb				
Azerbaijan	3	-1.519	2	-3.139
Kazakhstan	2	-2.908	1	-2.844
Kyrgyzstan	1	-5.256	1	-4.982
Türkiye	4	-0.713	1	-2.136
Turkmenistan	1	-1.643	2	-1.597
Uzbekistan	1	-1.496	1	-1.623
Panel		-2.256		-2.720
lnmff				
Azerbaijan	1	-4.795	1	-5.220
Kazakhstan	1	-1.172	1	-1.084
Kyrgyzstan	3	-2.002	3	-2.590
Türkiye	1	-1.799	4	-3.020
Turkmenistan	1	-3.047	1	-2.326

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

Uzbekistan	1	-1.116	1	-1.390
Panel		-2.322		-2.605
Lnmfm				
Azerbaijan	1	-2.823	1	-2.918
Kazakhstan	1	-3.331	1	-3.255
Kyrgyzstan	2	-2.424	3	-1.074
Türkiye	3	-1.797	4	-3.474
Turkmenistan	1	-3.131	1	-4.359
Uzbekistan	1	-2.899	1	-2.489
Panel		-2.734		-2.928
Lnmfnm				
Azerbaijan	1	-0.928	1	-1.467
Kazakhstan	1	-3.315	1	-3.391
Kyrgyzstan	1	-0.956	1	-3.414
Türkiye	1	-2.698	1	-2.633
Turkmenistan	1	-2.101	1	-2.710
Uzbekistan	2	-2.362	2	-2.168
Panel		-2.060		-2.631

Note: *, *, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. The maximum lag order is 4, with the optimal lag selected using the Schwarz information criterion (SIC). Critical values are from Pesaran (2007).

Source: Compiled by the authors

Following the identification of cross-sectional dependence and slope heterogeneity, the stationarity properties of the variables were examined using the Pesaran (2007) CADF panel unit root test, with the results reported in Table 5. The CADF critical values are −4.11, −3.36, and −2.97 for the constant model and −4.67, −3.87, and −3.49 for the constant-plus-trend model. The corresponding panel critical values are −2.57, −2.33, and −2.21, and −3.10, −2.86, and −2.73, respectively (Pesaran, 2007, pp. 275–281). The results indicate that both economic growth and material footprint components are generally non-stationary in levels under the intercept-only and intercept-and-trend specifications. Although some country-level results suggest stationarity for specific variables, this pattern is not consistent across the panel. After first differencing, the variables were found to be stationary. These additional results are not reported for brevity but are available upon request.

Given the common order of integration, the long-run association between economic growth and material footprint components was subsequently examined using panel cointegration tests that account for structural breaks. This step is important for assessing whether growth-related material pressure follows a stable

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

long-run pattern or whether the relationship is disrupted by structural changes in the Turkic Republics.

Table 6

Westerlund and Edgerton (2008) Structural Break Cointegration Test

	Z_τ (N)		Z_φ (N)	
MODEL	**Stats.**	**p-value**	**Stats.**	**p-value**
No break	-1.63245*	0.05129	-2.23437**	0.01273
Level break	-0.76021	0.22356	-0.30985	0.37834
Regime shift	1.52513	0.93639	1.38211	0.91653

	years	
	Level break	**Regime shift**
Azerbaijan	2005	1992
Kazakhstan	1993	1992
Kyrgyzstan	2019	1992
Türkiye	2000	2000
Turkmenistan	1996	1996
Uzbekistan	1994	1994

Note: ***, ** and * respectively indicate statistical significance levels of 1%, 5% and 10%. The trim was taken at 0.10.

Source: Compiled by the authors

The Westerlund and Edgerton (2008) panel cointegration test with structural breaks was employed to examine the long-run association between economic growth and material footprint components in the presence of structural shifts; the results are presented in Table 6. The results provide limited evidence of cointegration in the no-break specification; however, this evidence disappears once structural breaks are incorporated. In particular, the panel statistics lose significance under the regime-shift specification, indicating the absence of a stable long-run equilibrium relationship. The estimated break dates largely coincide with the post-Soviet transition period and the structural transformations of the 2000s, suggesting that growth–material footprint dynamics in these economies reflect structural changes and external shocks rather than stable long-run trends. Overall, these findings do not provide evidence of a sustained material decoupling pattern across the panel.

Given the limited evidence of a stable cointegrating relationship, the analysis proceeds with the Emirmahmutoglu and Kose (2011) panel causality test to examine the direction of causality in the short and medium term. Although the baseline specification focuses on the growth-driven material pressure channel, the causality analysis is conducted in both directions to account for possible feedback effects between economic growth and material footprint components. In this framework, the *lnGDP → lnMF* columns columns indicate whether economic growth

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

generates material pressure, whereas the reverse-direction columns indicate possible feedback effects of material footprint components on economic growth.

Table 7

Bidirectional Panel Causality between Economic Growth and Material Footprint Components

Panel A. Growth-driven material pressure

Countries	lnGDP → lnMFB	lnGDP → lnMFF	lnGDP → lnMFM	lnGDP → lnMFNM
Azerbaijan	*1.971(0.373)*	*1.031(0.597)*	*2.029(0.362)*	*2.963(0.227)*
Kazakhstan	*0.140(0.932)*	*5.092(0.165)*	*1.860(0.601)*	*28.508*** (0.000)*
Kyrgyzstan	*0.781(0.853)*	*2.430(0.488)*	*0.573(0.902)*	*4.537(0.208)*
Türkiye	*5.787(0.998)*	*0.334(0.562)*	*0.203(0.652)*	*0.058(0.808)*
Turkmenistan	*1.880(0.597)*	*7.414*(0.059)*	*2.372(0.305)*	*11.312*** (0.010)*
Uzbekistan	*2.541(0.467)*	*3.851(0.277)*	*0.263(0.966)*	*0.901(0.825)*
Fisher	*4.981(0.958)*	*15.411(0.219)*	*6.544(0.886)*	*41.626*** (0.000)*

Panel B. Feedback effects from material footprint to economic growth

Countries	lnMFB→ lnGDP	lnMFF→ lnGDP	lnMFM→ lnGDP	lnMFNM→ lnGDP
Azerbaijan	*0.456(0.795)*	*0.555(0.757)*	*1.586(0.452)*	*9.757***(0.008)*
Kazakhstan	*2.475(0.290)*	*1.099(0.777)*	*0.763(0.858)*	*0.323(0.956)*
Kyrgyzstan	*5.259(0.153)*	*2.344(0.503)*	*2.168(0.538)*	*0.246(0.970)*
Türkiye	*1.057(0.303)*	*0.073(0.785)*	*0.051(0.820)*	*0.017(0.897)*
Turkmenistan	*4.807(0.186)*	*1.150(0.764)*	*1.224(0.542)*	*1.146(0.766)*
Uzbekistan	*4.080(0.252)*	*8.862**(0.031)*	*3.164(0.366)*	*4.717(0.194)*
Fisher	*15.169(0.232)*	*10.384(0.582)*	*6.754(0.873)*	*13.943(0.304)*

Note: Values in parentheses are p-values. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. The arrows indicate the direction of Granger causality. For example, lnGDP → lnMFNM tests whether economic growth Granger-causes non-metallic mineral footprint, while lnMFNM→lnGDP tests the reverse feedback effect.

Source: Compiled by the authors

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

The results of the bidirectional panel causality test reported in Table 7 indicate that the relationship between economic growth and material footprint components is material-specific. Panel A shows no statistically significant evidence of panel-level causality from *lnGDP* to biomass, fossil fuel, or metal ore footprints. This suggests that economic expansion does not appear to generate uniform material pressure across all resource categories in the Turkic Republics. Instead, the growth–resource nexus appears to depend on the specific type of material considered.

The most notable result concerns non-metallic minerals. The panel Fisher provides evidence of statistically significant unidirectional causality from *lnGDP* to *lnMFNM*. This finding suggests that economic growth in the Turkic Republics increases the demand for non-metallic minerals, which are closely associated with construction activity, infrastructure investment, urban expansion, cement and aggregate use, and the development of logistics infrastructure. Therefore, the main material channel through which economic growth generates resource pressure in the region appears to be non-metallic mineral consumption.

Panel B provides limited evidence of reverse feedback effects from material footprint components to economic growth. Although some country-specific causal relationships are observed, these effects do not translate into statistically significant panel-level causality. In particular, the absence of statistically significant evidence of panel-level causality from *lnMFNM* to *lnGDP* suggests that non-metallic mineral use does not function as an independent driver of economic growth. Rather, it appears to reflect derived demand for materials generated by growth-oriented infrastructure projects, construction activity, and regional connectivity initiatives.

Overall, the causality results indicate that economic growth does not appear to generate uniform material pressure across all resource categories. Instead, growth-driven material pressure is concentrated in non-metallic minerals, indicating that infrastructure and construction-related material demand represents the dominant channel of resource pressure in the Turkic Republics. This result is also consistent with the weak cointegration evidence reported earlier, suggesting that growth–material interactions operate mainly through short – and medium-term, material-specific channels rather than through a stable long-run equilibrium relationship.

DISCUSSION AND FINDINGS

The empirical findings indicate that economic growth in the Turkic Republics places pressure on material use in a material-specific rather than uniform manner. The key result is the unidirectional causality running from GDP to non-metallic mineral use, suggesting that growth-oriented development patterns primarily increase demand for construction and infrastructure-related materials. This pattern is consistent with the material-intensive nature of infrastructure-led growth in transition economies, where economic expansion is often accompanied by rising demand for cement, aggregates, sand, gravel, and other non-metallic minerals (Kassouri et al., 2021; Krausmann et al., 2009). Similarly, Tekbaş (2022) argues that transition economies may experience periods of rapid resource-intensive development before achieving improvements in resource efficiency.

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

In the Turkic Republics, this result can be explained by the structural composition of growth. Since the beginning of the post-Soviet transition period, infrastructure expansion, urban development, transportation networks, energy-related investments, and regional logistics projects have played an important role in the development strategies of these economies. In particular, initiatives such as the "Middle Corridor" have increased the importance of construction, logistics, and connectivity-related investments in the region (Diriöz, 2022; Sönmez, 2021). Therefore, the significant causality from GDP to non-metallic mineral use should not be interpreted as evidence of a general effect on resource use but rather as evidence that growth creates material pressure mainly through infrastructure and construction-intensive channels.

From a decoupling perspective, the absence of stable long-run cointegration suggests limited evidence of sustained material decoupling in the region. This finding is consistent with studies showing that technological progress and efficiency gains are often insufficient to offset rising material demand, particularly in economies where growth remains linked to large-scale infrastructure and capital formation (Haberl et al., 2020; Nagano et al., 2025). Although carbon intensity and energy efficiency may improve over time, material consumption can continue to increase alongside economic growth. In this respect, the results support the argument that carbon decoupling does not necessarily imply material decoupling (Regueiro-Ferreira & Alonso-Fernández, 2023; Wiedmann et al., 2015).

The findings also have important implications for sustainable business strategies. Since growth-induced material pressure is concentrated mainly in the use of non-metallic minerals, firms operating in construction, infrastructure, logistics, manufacturing, and related supply chains need to integrate material efficiency into their production, procurement, and investment decisions. Sustainable procurement, the use of recycled inputs, circular construction practices, modular design, material-efficient technologies, and green supply-chain management may help reduce the environmental pressure associated with infrastructure-led growth. These practices are also relevant to business competitiveness, as resource efficiency can reduce production costs, improve supply-chain resilience, and support compliance with emerging sustainability standards.

Overall, the results suggest that emission-based indicators alone may not fully capture the environmental pressures associated with growth in transition economies. For the Turkic Republics, the main sustainability challenge is not only reducing emissions but also managing the material intensity of infrastructure and construction-driven development. Therefore, both policymakers and business actors should complement carbon-oriented strategies with material efficiency, circular economy practices, and resource-conscious production models. This integrated approach is essential for moving from resource-intensive growth toward more sustainable and competitive development pathways.

CONCLUSION AND POLICY IMPLICATIONS

This study examined whether economic growth is associated with material pressure in the Turkic Republics by focusing on disaggregated material footprint components over the 1992–2024 period. Using second-generation panel econometric techniques, the analysis investigated whether growth-oriented development patterns generate resource pressures that are stable over time and whether these pressures vary across material categories, while accounting for cross-

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

sectional dependence, heterogeneity, and structural breaks. The findings show that the growth–material nexus differs across material categories and does not exhibit a stable long-run equilibrium structure. The weak cointegration results under regime-shift specifications suggest that growth-related material dynamics in the region are shaped mainly by structural changes, cyclical factors, and external shocks rather than by a sustained material decoupling process.

The causality analysis indicates that economic growth does not have a statistically significant and consistent causal effect on biomass, fossil fuel, or metal ore footprints at the panel level. In contrast, statistically significant unidirectional causality is found to run economic growth to non-metallic mineral consumption. This finding suggests that the material pressure generated by economic expansion in the Turkic Republics is concentrated mainly in construction – and infrastructure-related resource use. Therefore, infrastructure-led development remains a key channel through which economic growth increases material pressure in the region.

These findings imply that environmental policies in the Turkic Republics should move beyond emission-oriented approaches and incorporate material efficiency into development planning. In particular, large-scale infrastructure, transportation, housing, and logistics projects should be designed with explicit resource-efficiency criteria. Public procurement policies may support this transition by prioritizing recycled inputs, durable materials, construction methods with lower material intensity, and circular project designs. Such measures are especially relevant to infrastructure and logistics investments associated with regional connectivity projects such as the Middle Corridor.

The policy implications may also differ across country groups within the region. For resource-rich economies such as Azerbaijan, Kazakhstan, and Turkmenistan, material efficiency standards should be integrated into energy infrastructure, industrial investment, and construction-related projects. For economies such as Türkiye and Uzbekistan, where urban development, manufacturing, logistics, and construction play a more prominent role, green public procurement, circular construction practices, and construction and demolition waste recycling may be particularly important. For smaller economies such as Kyrgyzstan, incorporating principles for reducing material intensity into infrastructure planning may help reduce future resource dependence while supporting sustainable development.

From a business perspective, the results underline the need for firms operating in construction, infrastructure, logistics, manufacturing, and related supply chains to integrate resource efficiency into production, procurement, and investment decisions. Sustainable procurement, the use of recycled inputs, circular construction practices, modular design, material-efficient technologies, and green supply-chain management may reduce the environmental pressure associated with infrastructure-led growth. These practices may also strengthen business competitiveness by lowering material costs, improving supply-chain resilience, and supporting compliance with emerging sustainability standards.

Overall, sustainable development in the Turkic Republics requires an integrated approach that combines macro-level environmental policies with firm-level sustainability strategies. Such an approach can support the transition from resource-intensive growth toward more resource-efficient, circular, and sustainable economic and business models.

Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

Limitations and Future Research Directions

This study has several limitations. First, the sample is limited to six Turkic Republics due to the limited availability of comparable long-term data. Although this country group is analytically meaningful because of shared transition experiences and regional integration dynamics, the small cross-sectional dimension limits the generalizability of the findings and requires cautious interpretation of country-level heterogeneity. Second, the analysis focuses mainly on macroeconomic indicators, while institutional quality, financial development, digital transformation, foreign direct investment, and sectoral production structures may also influence resource productivity and material use.

Future research may extend the analysis by incorporating these additional determinants and by using sectoral, firm-level, or supply-chain data. Such studies could provide a more detailed understanding of the drivers of non-metallic mineral consumption and help identify how firms in construction, infrastructure, logistics, and manufacturing respond to material pressure through sustainable procurement, circular production practices, green supply-chain strategies, and resource-efficient business models.

Ethics Committee Approval

This study did not require ethics committee approval because it did not involve human participants, animals, or sensitive personal data. All data used in this research were obtained from publicly available sources.

Conflict of Interest Statement

There is no conflict of interest with any institutions or person within the scope of this study.

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Eurasian Research Journal
Summer 2026
Vol. 8, No. 3

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