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Research Article

The Relationship Between Sustainable Construction and Economic Growth for Reinforced Concrete Structures in Türkiye

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ABSTRACT

The construction sector is one of the key industries in terms of sustainable development. It plays a growing role in addressing issues such as sustainable cities, responsible production, and consumption, which are among the sustainable development goals set for Türkiye. Additionally, these goals aim to decouple economic growth from environmental degradation. The construction sector is also one of the industries contributing to environmental degradation. In order to reduce this degradation and ensure environmental sustainability, the vision of sustainable construction is emerging. Specifically, CO_2 emissions from building materials in the sector are considered one of the causes of environmental degradation. This study aims to determine the decoupling of economic growth from environmental degradation for reinforced concrete structures in the construction sector in line with Türkiye's sustainable development goals. By examining the relationship between embedded CO_2 emissions from the raw construction materials (concrete and reinforcement) used in the reinforced concrete structures built in Türkiye and economic growth, the study classifies the type of decoupling. It evaluates 12 statistical regions separately for the period from 2010 to 2019. As a result, weak decoupling was observed in four statistical regions, while strong decoupling was seen in the other regions. Weak decoupling was identified in the regions of Istanbul (TR1), East Marmara (TR4), Mediterranean (TR6), and Central Anatolia (TR7).

Keywords: *Sustainable development, CO_2 emissions, Decoupling, Construction sector, Sustainable construction*

Türkiye'de Betonarme Yapılar için Sürdürülebilir İnşaat ve Ekonomik Büyüme Arasındaki İlişki

ÖZ

İnşaat sektörü, sürdürülebilir kalkınma açısından önemli sektörlerden biridir. Türkiye için belirlenen sürdürülebilir kalkınma hedefleri arasında yer alan sürdürülebilir şehirler, sorumlu üretim ve tüketim gibi konuların ele alınmasında giderek artan bir rol oynamaktadır. Ayrıca bu hedefler ekonomik büyümeyi çevresel bozulmadan ayırmayı amaçlamaktadır. İnşaat sektörü de çevresel bozulmaya katkıda bulunan endüstrilerden biridir. Bu çevresel bozulmanın azalması ve çevresel sürdürülebilirliğin sağlanması amacı ile sürdürülebilir inşaat vizyonu oluşturulmuştur. Sektörde özellikle yapı malzemelerindeki CO_2 emisyonları çevresel bozulma sebepleri arasında gösterilmektedir. Bu çalışma Türkiye'deki betonarme yapılar için sürdürülebilir kalkınma amaçları doğrultusunda inşaat sektöründe ekonomik büyümenin çevresel bozulmadan ayrıklaştırma durumunu belirlemeyi hedeflenmektedir. Çalışma, Türkiye'deki inşa edilen betonarme yapıların kaba inşaat malzemelerindeki (beton ve donatı) gömülü CO_2 emisyonu ile ekonomik büyüme arasındaki ilişkiyi inceleyerek, ayrıklaştırma türünü sınıflandırmaktadır. Çalışmada 2010-2019 yılları arasında 12 istatistiki bölge için ayrı ayrı değerlendirme yapmaktadır. Sonuç olarak dört istatistiksel bölgede zayıf ayrıklaştırma gözlemlenirken, diğer bölgelerde güçlü

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ayrıklaştırma görülmüştür. Zayıf ayrıklaştırma; İstanbul (TR1), Doğu Marmara (TR4), Akdeniz (TR6) ve Orta Anadolu (TR7) bölgelerinde tespit edilmiştir.

Anahtar kelimeler: *Sürdürülebilir kalkınma, CO_2 emisyonu, Ayrıştırma, İnşaat sektörü, Sürdürülebilir inşaat*

I. INTRODUCTION

The construction sector supports environmental, economic, and social elements in terms of sustainable development. The construction sector plays a significant role in economic growth in terms of employment, due to its broad scope and diversity of inputs [1]. It also has significant social impacts by contributing to the construction of essential living and social spaces that enhance quality of life. Furthermore, its integration of structures and the environment as parts of a whole underscores its importance for environmental sustainability [2,3]. The concept of "sustainable construction" has also come to the forefront in the sector alongside the principles of sustainable development [2].

Sustainable construction is defined as "the creation of an environment where resources are used efficiently, based on ecological principles, and managed responsibly" [4,5]. Globally, sustainable construction encompasses a socioeconomic and environmental perspective while also possessing a national and regional vision [5,6]. It plays a significant role in addressing sustainability-related challenges [7].

With the increase in industrialization in developing countries, rapid urbanization is occurring, leading to a growing demand for buildings and infrastructure [8,9]. This demand results in significant resource consumption in the construction sector. Since many of these resources include emission-intensive materials such as cement, steel, and concrete, the construction sector is a major contributor to CO_2 emissions [9-15]. In 2019, global greenhouse gas emissions from buildings accounted for 21% of total global emissions. Furthermore, 18% of greenhouse gas emissions were attributed to the production of cement and steel used in building construction [16].

The majority of greenhouse gas emissions from the construction sector are CO_2 emissions, with approximately 40% of global annual emissions stemming from buildings and infrastructure [16,17]. Among embedded CO_2 emissions in the sector, concrete (30%) and steel (25%) rank as the top contributors [17]. If necessary measures are not taken by 2050, global concrete usage could result in 3.8 billion tons of CO_2 emissions [18].

The Paris Agreement, which came into effect in 2020, places the responsibility for reducing emissions on participating nations and aims to limit global warming to below 2°C compared to pre-industrial levels [19,20]. The cement and concrete sectors play a critical role in achieving this target [21]. Resource efficiency in structural materials such as steel and cement are declining, particularly in developing economies, where structural material resources are being rapidly depleted [22].

According to the United Nations Sustainable Development Goals, global resource efficiency in consumption and production must be progressively improved by 2030, and efforts should be made to decouple economic growth from environmental degradation [23]. Decoupling is defined by the European Union as "reducing the adverse effects arising from the use of natural resources in a growing economy" [24-25].

Today, the relationship between economic growth and environmental degradation has been extensively studied across various industrial sectors for sustainable production and development. In the literature, there are studies focusing on environmental pollution in the construction sector [26-31] and sustainable construction [3, 32-34]. Yılmaz et al. [32] examined the threats and opportunities for a sustainable construction sector. The authors emphasized the importance of designing integrated technological roadmaps involving all stakeholders for sustainable buildings [32]. Gökçe et al. [3] analyzed national legal regulations and standards developed specifically for sustainable construction in Türkiye, incorporating internationally recognized standards as well. The result of the study emphasizes the need for training and incentive programs aimed at sustainable construction in the industry [3]. Hwang et al. [33] investigated the barriers and solutions for the adoption of sustainable construction practices by small contractors. The greatest barrier identified was the need for additional investment [33]. The study also explored the economic challenges in sustainable construction, concluding that market-driven measures in construction economics are strategically more effective [34].

According to Osuizugbo et al. [35], adopting sustainable construction practices in the construction industry significantly reduces the greenhouse gas emissions generated by the sector. In this context, the researchers have explored the variables that hinder the effective adoption of sustainable construction practices in the Nigerian construction sector and the possible solutions. As a result, they have stated that the government should take a larger role in promoting the sustainability of the sector. [35].

Tapio [26] examined the relationship between GDP, traffic volumes, and CO_2 emissions from transportation in the EU15 countries. As a result of the study, it was determined that in Finland, CO_2 emissions from road traffic were strongly decoupled from road traffic volume, while GDP was weakly decoupled from road traffic volume [26]. Du et al. [27] investigated the relationship between economic growth and carbon emissions caused by the construction industry in China, while Su et al. [28] focused on the supply chain, and Ogungbile et al. [29] included various sectors in their analysis. In the Su et al. [28] study, non-competitive input-output models at comparable prices for different years and the Structural Production Layer Difference (SPLD) method have been used. As a result, it has been determined that the direct impact of other service sectors and transportation-storage on carbon emissions in the construction sector was not highlighted by the structural decomposition analysis [28]. According to the results of the study conducted by Ogungbile et al. [29], it has been determined that the construction sector in Gansu, Xinjiang, Ningxia, and Inner Mongolia has significant CO_2 emission interactions compared to other provinces, and the construction sector is identified as the critical sector for these regions [29]. In a study by Artekin [30], the relationship between the construction sector, employment, and economic growth in Türkiye from 2005 to 2023 was analyzed. Zivot-Andrews (ZA) unit root, Phillips-Perron (PP) unit root, and GMM tests have been applied in the analysis. A bidirectional relationship was observed between the construction sector and economic growth [30]. Wang et al. [36] conducted research on the decoupling of economic growth and construction waste production. This study, which offered a comparative analysis between the China and EU, aimed to develop construction waste management theories and promote sustainable development. In this study, the Tapio, Kaya, and LMDI methods have been used. They have determined that the construction waste generation in China is in a weak decoupling situation [36]. Wong et al. [10] explored the adoption of carbon reduction strategies by Australian construction contractors. In this study, an evaluation based on a survey has been conducted [10]. Wu et al. [12] determined the type of decoupling between carbon emissions and economic output in the Chinese construction sector. This study has examined decoupling relationships at both national and state levels from 2005 to 2015 using the Tapio decoupling model [12]. Dobrucali [31] analyzed the relationship between embedded CO_2 emissions from ready-mix concrete production, environmental pollution, and economic growth. The decoupling method used by Tapio has been applied in the study. This study, conducted for 20 OECD countries, identified the types of decoupling during the Kyoto Protocol commitment periods. According to the results of the study, absolute decoupling between environmental degradation and economic growth has been observed in Switzerland and Belgium [31].

Overall, when a literature review is conducted, it can be observed that there are a few studies examining the relationship between environmental pollution and economic growth. It has been determined that studies specifically focusing on Türkiye’s construction sector in this context are almost non-existent.
According to the author's knowledge, there are very few studies in the literature on decoupling economic growth from environmental degradation in the construction sector. This study has been conducted to contribute to the literature and investigate the situation of decoupling economic growth from environmental degradation in the construction sector.

This study investigates the relationship between embedded CO_2 emissions from the primary construction materials (concrete and reinforcement) used in reinforced concrete structures in Türkiye and economic growth. It examines a 10-year period (2010–2019) prior to the Paris Agreement, providing an overview of the state of the construction sector before the agreement and contributing to sustainable construction and sustainable development.

II. MATERIAL AND METHODS

This study examines the relationship between embedded CO_2 emissions from primary construction materials (concrete and reinforcement) used in reinforced concrete structures and economic growth across 12 statistical regions in Türkiye. The study consists of four main stages. The first stage involves defining the analysis region and period, the second stage focuses on compiling the analysis data, the third stage applies the decoupling analysis method to determine the type of decoupling, and the final stage evaluates the analysis results. The methodology of the study is illustrated in Figure 1.

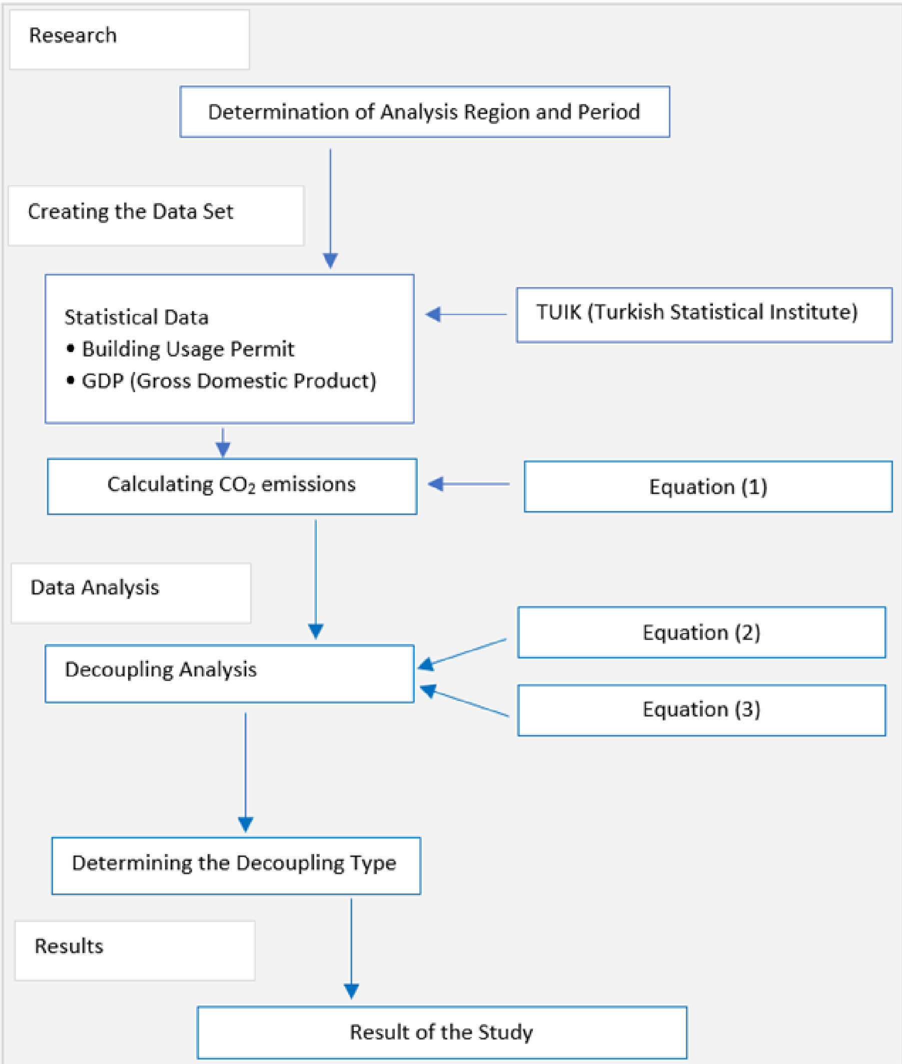

Figure 1. *Study Methodology*

A. DETERMINING THE ANALYSIS REGION AND PERIOD

The study focuses on 12 regions, selected based on the classification of Statistical Regional Units for Development Planning in Türkiye, coordinated by the State Planning Organization (DPT) and the Turkish Statistical Institute (TUIK) [37]. This classification includes:

TR1 (Istanbul): Istanbul;
TR2 (Western Marmara): Tekirdağ, Balıkesir, Kırklareli, Çanakkale, Edirne;
TR3 (Aegean): İzmir, Denizli, Aydın, Muğla, Afyonkarahisar, Kütahya, Manisa, Uşak;
TR4 (Eastern Marmara): Bursa, Bilecik, Eskişehir, Kocaeli, Sakarya, Bolu, Düzce, Yalova;
TR5 (Western Anatolia): Ankara, Karaman, Konya;
TR6 (Mediterranean): Antalya, Burdur, Isparta, Mersin, Adana, Kahramanmaraş, Hatay, Osmaniye;
TR7 (Central Anatolia): Kırıkkale, Niğde, Aksaray, Kırşehir, Nevşehir, Sivas, Kayseri, Yozgat;
TR8 (Western Black Sea): Zonguldak, Bartın, Karabük, Çankırı, Kastamonu, Samsun, Sinop, Çorum, Tokat, Amasya;
TR9 (Eastern Black Sea): Trabzon, Giresun, Ordu, Artvin, Rize, Gümüşhane;
TRA (North eastern Anatolia): Erzurum, Erzincan, Ağrı, Bayburt, Iğdır, Kars, Ardahan;
TRB (Central Eastern Anatolia): Malatya, Bingöl, Elazığ, Tunceli, Muş, Van, Bitlis, Hakkari;
TRC (South eastern Anatolia): Gaziantep, Kilis, Adıyaman, Şanlıurfa, Mardin, Diyarbakır, Şırnak, Batman, Siirt.

These regions are used with the abbreviations mentioned above. The study covers the period between 2010 and 2019, prior to the Paris Agreement. While the Paris Agreement applies to data from 2020 onwards, the year 2020 was not included in this study. This is due to the fact that the COVID-19 pandemic, which began in 2020, caused restrictions that had a significant impact on the construction sector.

B. CREATION OF ANALYSIS DATA

In this study, the embedded CO_2 emissions in the primary construction materials (concrete and reinforcement) of reinforced concrete structures were calculated based on building use permit data. These data include all construction type classifications, excluding industrial buildings. Industrial buildings were excluded from the analysis because steel construction is used much more extensively in these buildings compared to other construction types. Economic growth was correlated with GDP (Gross Domestic Product). The building use permit and GDP data for the study years and regions were obtained from the TUIK database [38]. The study covers 12 regions defined by the Statistical Region Units Classification for Development Planning in Türkiye, established under the coordination of the State Planning Organization (DPT) and the Turkish Statistical Institute (TUIK) [37].

For the study, it was assumed that the buildings with building use permits used C25 concrete and S420 steel in their construction. In the literature, there are coefficient values for floor area and measurement calculation (0.38 m^3/m^2 for concrete; 0.034 tons/m^2 for steel) [39]. Using the total floor area values and these coefficients, the amounts of concrete and reinforcement were calculated. Additionally, the CO_2 values for C25 concrete and S420 steel were calculated based on studies from the literature. The unit CO_2 value for C25 concrete was taken as an average of 226 kg/m^3 [40, 41] (The average value from the studies by Mergos [40] and de Medeiros & Kripka [41] was used.), and for S420 steel, it was taken as an average of 352 kg/ton [42]. The total CO_2 values for the years 2010–2019 were calculated using Equation (1) and are shown in Table 1 and Figure 2.

$$T = Y_N(M_c x C + M_s x S) \tag{1}$$

In Equation (1), T represents the total CO_2 amount, M_c is the measurement coefficient for concrete, C is the unit CO_2 amount for concrete (C25), M_s is the measurement coefficient for reinforcement steel, and S is the unit CO_2 amount for steel (S420).

Table 1. CO_2 amount and GDP for statistical regions

Region	Year	Building use permit (m^2)	Total CO_2 (ton)	GDP (Based on 2009) (Thousand TRY)	GDP (Based on 2009) (Thousand USD)
TR1	2010	11,135,446	1,099,035.37	340,511,117.00	221,456,241.55
	2011	18,008,976	1,773,810.56	414,109,741.00	219,233,279.16
	2012	17,170,770	1,693,066.79	474,537,629.00	266,954,111.72
	2013	23,532,507	2,315,820.99	556,694,426.00	261,309,813.18
	2014	26,654,231	2,622,559.10	631,564,008.00	271,418,629.08
	2015	24,747,279	2,428,149.50	727,311,453.00	249,241,442.38
	2016	27,304,475	2,682,312.51	811,518,936.00	230,597,560.81
	2017	27,659,178	2,716,244.58	973,837,089.00	258,182,106.90
	2018	27,915,281	2,743,173.42	1,159,274,030.00	219,517,900.02
	2019	24,660,811	2,423,875.98	1,325,199,566.00	223,097,570.03
TR2	2010	7,270,110	717,000.40	53,923,382.00	35,069,837.41
	2011	7,095,831	700,530.46	63,412,142.00	33,570,936.52
	2012	7,315,466	721,521.64	70,296,672.00	39,545,832.58
	2013	7,551,350	744,866.26	77,758,672.00	36,499,564.40
	2014	8,586,869	846,167.69	89,527,539.00	38,475,026.43
	2015	8,072,678	794,327.29	101,535,098.00	34,794,934.38
	2016	10,134,373	995,001.51	115,785,133.00	32,900,981.19
	2017	13,162,990	1,293,696.64	138,404,151.00	36,693,483.66
	2018	8,760,697	862,316.26	168,995,702.00	32,000,701.00
	2019	3,304,882	325,658.81	195,678,907.00	32,942,576.94
TR3	2010	17,323,334	1,706,184.04	151,624,734.00	98,611,299.43
	2011	13,034,020	1,286,604.12	181,536,129.00	96,106,797.08
	2012	17,267,410	1,703,866.11	201,550,675.00	113,383,593.05
	2013	18,308,681	1,807,477.20	227,113,998.00	106,606,270.18
	2014	22,223,756	2,189,959.81	256,554,011.00	110,255,709.74
	2015	20,249,599	1,994,570.53	289,322,103.00	99,147,425.72
	2016	24,852,167	2,445,381.80	328,582,522.00	93,368,527.51
	2017	35,286,561	3,466,263.38	393,779,805.00	104,398,262.15
	2018	20,241,173	1,991,949.96	481,686,561.00	91,211,240.48
	2019	7,803,779	769,293.21	545,635,472.00	91,857,823.57
TR4	2010	9,332,759	923,649.26	129,250,396.00	84,059,830.91
	2011	11,815,418	1,170,772.18	159,689,985.00	84,541,259.46
	2012	12,815,253	1,268,532.12	177,108,473.00	99,633,479.41
	2013	15,039,781	1,490,107.26	205,083,616.00	96,265,309.80
	2014	16,071,590	1,591,194.79	232,237,852.00	99,805,686.54
	2015	14,703,945	1,452,357.29	267,592,002.00	91,700,764.88
	2016	16,055,451	1,587,143.50	296,276,028.00	84,188,459.88
	2017	18,819,933	1,854,176.06	363,023,993.00	96,244,331.24
	2018	21,764,699	2,150,216.07	448,760,465.00	84,976,418.29
	2019	16,696,825	1,649,158.08	496,345,678.00	83,559,878.45

Table 1 (cont). *CO_2 amount and GDP for statistical regions*

TR5	2010	20,793,585	2,044,492.46	136,501,751.00	88,775,852.63
	2011	20,039,160	1,970,157.92	163,975,572.00	86,810,086.29
	2012	22,461,037	2,211,236.63	184,144,943.00	103,591,889.63
	2013	25,507,821	2,509,060.89	218,674,158.00	102,644,647.95
	2014	30,892,463	3,041,942.21	241,103,632.00	103,615,811.59
	2015	23,718,681	2,333,225.53	273,437,161.00	93,703,835.03
	2016	25,471,244	2,507,785.80	313,169,029.00	88,988,698.85
	2017	40,892,797	4,020,330.43	361,369,604.00	95,805,722.32
	2018	16,006,244	1,582,684.28	425,587,933.00	80,588,512.21
	2019	8,029,738	797,941.52	502,764,108.00	84,640,422.22
TR6	2010	8,915,274	879,540.22	123,664,680.00	80,427,081.17
	2011	10,478,339	1,035,122.77	146,879,306.00	77,759,175.18
	2012	10,855,329	1,076,473.87	162,921,957.00	91,652,766.09
	2013	15,564,454	1,536,407.71	185,892,368.00	87,257,025.91
	2014	19,828,272	1,949,750.57	210,369,405.00	90,407,583.05
	2015	16,785,351	1,646,648.03	238,930,681.00	81,878,853.02
	2016	17,574,181	1,726,800.71	259,985,618.00	73,876,340.65
	2017	19,863,060	1,949,120.50	309,964,536.00	82,177,294.20
	2018	19,020,136	1,868,342.19	383,155,143.00	72,553,520.73
	2019	17,806,823	1,749,077.47	447,092,638.00	75,268,120.88
TR7	2010	5,150,119	506,496.95	46,073,924.00	29,964830.91
	2011	6,024,045	591,070.45	54,584,204.00	28,897,349.78
	2012	5,137,753	505,271.77	60,228,650.00	33,882,003.83
	2013	6,399,509	628,437.81	68,161,782.00	31,994,828.20
	2014	7,021,171	690,751.01	77,133,354.00	33,148,546.99
	2015	8,268,997	811,359.19	87,871,986.00	30,112,739.80
	2016	8,157,567	802,901.11	97,594,250.00	27,731,941.92
	2017	10,370,407	1,016,458.56	114,346,051.00	30,315,239.27
	2018	11,418,879	1,120,713.91	135,288,255.00	25,617,923.69
	2019	9,926,153	973,960.26	154,098,680.00	25,942,538.72
TR8	2010	12,937,147	1,284,250.43	50,907,437.00	33,108,376.74
	2011	4,435,414	436,537.49	59,780,509.00	31,648,318.60
	2012	7,170,475	704,477.66	65,074,916.00	36,608,301.08
	2013	7,543,257	740,204.29	72,432,728.00	33,999,590.69
	2014	9,436,086	927,224.26	81,866,302.00	35,182,561.35
	2015	7,912,211	777,060.37	92,825,892.00	31,810,387.58
	2016	10,055,018	987,048.18	103,102,956.00	29,297,270.97
	2017	15,744,983	1,542,623.69	120,936,784.00	32,062,563.69
	2018	8,796,934	865,741.73	140,558,516.00	26,615,890.17
	2019	3,289,491	323,859.90	158,970,449.00	26,762,701.85

Table 1 (cont). *CO_2 amount and GDP for statistical regions*

TR9	2010	9,371,187	918,114.05	28,034,398.00	18,232,568.94
	2011	2,490,075	244,380.98	32,687,789.00	17,305,198.26
	2012	4,591,992	450,156.63	37,025,186.00	20,828,750.00
	2013	5,671,780	556,325.68	41,047,946.00	19,267,717.80
	2014	7,620,040	747,010.86	46,081,737.00	19,803,918.09
	2015	5,045,865	496,842.94	55,953,238.00	19,174,544.40
	2016	5,949,183	584,006.28	58,859,489.00	16,725,246.93
	2017	8,018,212	786,506.69	68,630,098.00	18,195,100.08
	2018	5,639,125	553,407.89	79,029,556.00	14,964,884.68
	2019	2,760,144	270,706.35	94,610,423.00	15,927,680.64
TRA	2010	3,579,616	351,790.25	19,696,844.00	12,810,122.27
	2011	1,689,693	165,567.80	22,605,262.00	11,967,421.25
	2012	2,079,604	203,706.38	26,006,101.00	14,629,894.80
	2013	2,981,670	292,335.13	28,685,208.00	13,464,705.22
	2014	3,639,420	356,788.66	30,714,581.00	13,199,785.55
	2015	3,573,482	350,495.56	35,093,081.00	12,026,003.56
	2016	4,374,570	428,605.68	40,173,851.00	11,415,620.31
	2017	4,314,151	423,177.83	47,262,817.00	12,530,241.26
	2018	3,956,203	387,608.14	53,992,237.00	10,223,866.12
	2019	2,487,760	244,187.93	62,220,210.00	10,474,782.83
TRB	2010	10,076,075	987,669.14	28,279,260.00	18,398,998.05
	2011	2,962,922	290,670.42	33,977,193.00	17,987,819.90
	2012	5,701,821	558,719.87	39,985,569.00	22,494,131.98
	2013	5,578,413	547,394.25	43,880,355.00	20,597,237.61
	2014	5,313,343	521,129.65	48,289,155.00	20,752,569.94
	2015	6,190,717	606,524.34	54,416,244.00	18,647,833.86
	2016	6,921,920	678,020.03	61,789,897.00	17,557,938.45
	2017	8,685,845	852,279.47	73,613,726.00	19,516,351.44
	2018	6,813,149	667,746.82	86,628,713.00	16,403,846.43
	2019	4,281,631	419,777.81	101,419,632.00	17,074,012.12
TRC	2010	13,899,831	1,364,484.45	59,196,554.00	38,499,319.72
	2011	6,900,899	677,533.26	71,689,784.00	37,953,191.80
	2012	12,134,268	1,190,616.03	82,598,480.00	46,466,291.63
	2013	13,796,119	1,353,688.73	98,002,057.00	46,001,716.58
	2014	18,822,132	1,846,771.54	109,456,252.00	47,039,516.95
	2015	14,878,574	1,458,059.48	126,652,406.00	43,402,352.90
	2016	13,412,320	1,316,615.58	139,722,001.00	39,702,773.64
	2017	18,737,144	1,837,104.61	168,535,614.00	44,681,888.17
	2018	13,096,768	1,286,856.74	198,208,447.00	37,532,370.20
	2019	7,068,252	696,033.28	233,774,062.00	39,355,902.69

Note: The building use permit and GDP data in the table were obtained from TUIK [38]. The total CO_2 values were calculated by the author. Dollar accounts for GDP were calculated by the author, considering the Central Bank of the Republic of Türkiye [43-52] dollar exchange rate on the last day of the relevant year. (TRY: Turkish

Lira, USD: American dollar)

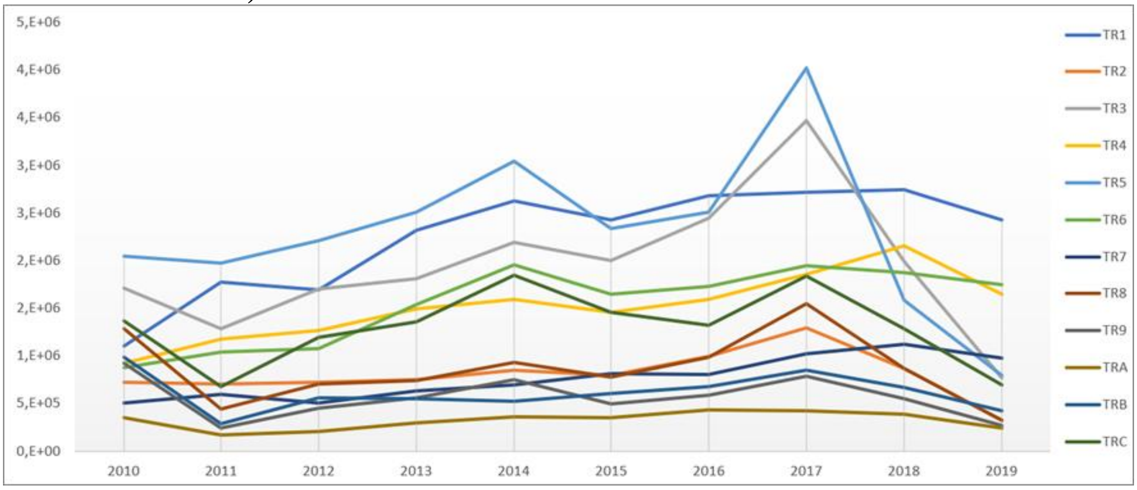

Figure 2. *Total CO_2 Emission (tons)*

In this study, to determine the relationship between environmental degradation caused by embedded CO_2 emissions in the primary construction materials (concrete and reinforcement) of reinforced concrete structures and economic growth, the ΔCO_2 and ΔGDP values were calculated separately for each statistical region. Equations (2) and (3) were used to calculate these values [26,31,53, 54]. The calculated values are presented in Table 2.

$$\Delta CO_2 = \left(\frac{CO_{2(2019)} - CO_{2(2010)}}{CO_{2(2010)}}\right) \times 100 \tag{2}$$

In Equation 2, ΔCO_2 represents the CO_2 value for the analysis period, CO_2 (2019) represents the CO_2 value for the year 2019, and CO_2 (2010) represents the CO_2 value for the year 2010.

$$\Delta GDP = \left(\frac{GDP_{(2019)} - GDP_{(2010)}}{GDP_{(2010)}}\right) \times 100 \tag{3}$$

In Equation 3, ΔGDP represents the GDP value for the analysis period, GDP (2019) represents the GDP value for the year 2019, and GDP (2010) represents the GDP value for the year 2010.

Table 2. *ΔCO_2 and ΔGDP values for statistical regions.*

Region	ΔCO_2 (%)	ΔGDP (%)	$\Delta CO_2/\Delta GDP$
TR1	120.55	289.18	0.42
TR2	-54.58	262.88	-0.21
TR3	-54.91	259.86	-0.21
TR4	78.55	284.02	0.28
TR5	-60.97	268.32	-0.23
TR6	98.86	261.54	0.38
TR7	92.29	234.46	0.39
TR8	-74.78	212.27	-0.35
TR9	-70.51	237.48	-0.30
TRA	-30.59	215.89	-0.14
TRB	-57.50	258.64	-0.22
TRC	-48.99	294.91	-0.17

Note: TRY values were used in ΔGDP calculations. Negative values in this table indicate that the 2010 values are higher than the 2019 values.

In this study, the relationship between CO_2 emissions and GDP was evaluated considering the decoupling categories defined by Tapio [26]. The reason for using the method applied by Tapio is its simpler understanding compared to other analysis methods and its greater suitability for the dataset. Tapio (2005) identified eight types of decoupling. These decoupling types are detailed in Table 3.

Table 3. *Types of decoupling [26]*

ΔCO_2	ΔGDP	$\Delta CO_2/\Delta GDP$	Types of decoupling
>0	<0	<0	Strong negative decoupling
	>0	0-0.8	Weak decoupling
	>0	0,8-1,2	Recessive coupling
	>0	>1,2	Expansive negative decoupling
<0	>0	<0	Strong decoupling
	<0	0-0.8	Weak negative decoupling
	<0	0,8-1,2	Expansive coupling
	<0	>1,2	Recessive decoupling

III. FINDINGS AND DISCUSSION

The study consists of the following stages: determining the region and period, generating analytical data, and defining the disaggregation analysis method and type. In the Material and Method section, the study's boundaries, scope, dataset creation, and analysis methods were described, and Tables 2 and 3 were created to determine the types of disaggregation.

In this section, based on Tables 2 and 3, the type of disaggregation between environmental degradation caused by embedded CO_2 emissions in the primary construction materials (concrete and reinforcement) of reinforced concrete buildings constructed during the analysis period (2010–2019) and economic growth linked to GDP is determined. The analysis results for 12 statistical regions are presented in Table 4.

According to these results, strong decoupling was observed in 8 regions, while weak decoupling was noted in 4 regions. Strong decoupling was observed in the following regions: TR2 (West Marmara), TR3 (Aegean), TR5 (West Anatolia), TR8 (West Black Sea), TR9 (East Black Sea), TRA (Northeast Anatolia), TRB (Central Anatolia), TRC (Southeast Anatolia). Weak decoupling was observed in the following regions: TR1 (Istanbul), TR4 (East Marmara), TR6 (Mediterranean), TR7 (Central Anatolia).

Table 4. *Analysis results*

Region	*ΔCO_2 (%)*	*ΔGDP (%)*	*$\Delta CO_2/\Delta GDP$*	*Types of decoupling*
TR1	*120.55>0*	*289.18>0*	*0.42>0*	*Weak decoupling*
TR2	*-54.58<0*	*262.88>0*	*-0.21<0*	*Strong decoupling*
TR3	*-54.91<0*	*259.86>0*	*-0.21<0*	*Strong decoupling*
TR4	*78.55>0*	*284.02>0*	*0.28>0*	*Weak decoupling*
TR5	*-60.97<0*	*268.32>0*	*-0.23<0*	*Strong decoupling*
TR6	*98.86>0*	*261.54>0*	*0.38>0*	*Weak decoupling*
TR7	*92.29>0*	*234.46>0*	*0.39>0*	*Weak decoupling*
TR8	*-74.78<0*	*212.27>0*	*-0.35<0*	*Strong decoupling*
TR9	*-70.51<0*	*237.48>0*	*-0.30<0*	*Strong decoupling*
TRA	*-30.59<0*	*215.89>0*	*-0.14<0*	*Strong decoupling*

TRB	*-57.50<0*	*258.64>0*	*-0.22<0*	*Strong decoupling*
TRC	*-48.99<0*	*294.91>0*	*-0.17<0*	*Strong decoupling*

IV CONCLUSION

The construction sector, in addition to being one of the leading sectors of the national economy, holds a significant position in terms of sustainable development. Its multi-stakeholder structure influences numerous other sectors. In other words, any step taken towards economic and sustainability issues in the construction sector will have ripple effects across other sectors. Many of Türkiye's sustainable development goals, such as sustainable cities and responsible production and consumption, are directly or indirectly related to the construction sector. One of these goals, decoupling economic growth from environmental degradation, is particularly relevant to the sector.

The Paris Agreement, which Türkiye is a party to, highlights the increasing temperatures caused by environmental degradation, especially greenhouse gas (CO_2 and others) emissions. The construction sector is one of the industries contributing to this degradation. To mitigate this and ensure environmental sustainability, a vision for sustainable construction has been developed. Specifically, CO_2 emissions from construction materials in the sector are considered one of the causes of environmental degradation. This study aims to determine the decoupling state of economic growth from environmental degradation in the construction sector, aligning with Türkiye's sustainable construction and development objectives. It examines the relationship between embedded CO_2 emissions from primary construction materials (concrete and reinforcement) in reinforced concrete buildings and economic growth in Türkiye, classifying the type of decoupling observed.

The study covers 12 regions defined by the Statistical Region Units Classification for Development Planning in Türkiye [37], established under the coordination of the State Planning Organization (DPT) and the Turkish Statistical Institute (TUIK). The study period spans the decade preceding the Paris Agreement (2010–2019). The decoupling analysis and type determination were conducted using the method applied by Tapio (2005).

The results of the analysis indicate the presence of only two types of decoupling: strong and weak decoupling. In strong decoupling, both ΔCO_2 and $\Delta CO_2/\Delta GDP$ have negative values, while ΔGDP has a positive value. In weak decoupling, ΔCO_2 and ΔGDP have positive values, while $\Delta CO2/\Delta GDP$ falls between 0 and 0.8. In other words, in strong decoupling, GDP has increased while CO_2 has decreased during the analysis period. In weak decoupling, both GDP and CO_2 have increased, but the rate of increase has not exceeded 0.8 (Table 3). Strong decoupling was observed in 8 regions: TR2 (West Marmara), TR3 (Aegean), TR5 (West Anatolia), TR8 (West Black Sea), TR9 (East Black Sea), TRA (Northeast Anatolia), TRB (Central Anatolia), TRC (Southeast Anatolia). Weak decoupling was observed in 4 regions: TR1 (Istanbul), TR4 (East Marmara), TR6 (Mediterranean), TR7 (Central Anatolia).

In the 8 regions with strong decoupling, the total GDP was 1,895,073,263 TL, and CO_2 emissions amounted to 3,847,458.81 tons. In the 4 regions with weak decoupling, the total GDP was 2,422,736,562 TL, and CO_2 emissions were 6,796,071.79 tons. These results indicate that the CO_2 emissions and GDP values in regions with weak decoupling are significantly higher than those in regions with strong decoupling, negatively impacting Türkiye's overall decoupling status.

An examination of the regions with weak decoupling reveals a concentration of industrial zones. It is estimated that the increased need for buildings driven by employment opportunities in these industrial zones has contributed to this outcome. The building use permit statistics in 2019 also support this finding, with 69,090,612 m² in regions with weak decoupling compared to 39,025,677 m² in regions with strong decoupling in 2019. The increased use of sustainable materials, such as low-carbon concrete, in the construction sector will contribute to reducing CO_2 emissions, thus helping to minimize environmental degradation. As economic growth increases and environmental degradation decreases, strong decoupling can be achieved in all regions.

The results of this study reflect the situation of the construction sector's reinforced concrete building production before the Paris Agreement, in line with Sustainable Development Goal 8.4. The key constraint of this study is that the data from statistical regions specifically pertains to reinforced concrete buildings. Other types of structures, aside from reinforced concrete buildings, have not been included in this study. According to these results, decoupling has occurred in all regions, but in regions with weak decoupling, measures need to be taken. It also indicates that more work is needed in the construction sector to decouple economic growth from environmental degradation. In the future, analyses can be conducted for periods under the Paris Agreement, allowing for a comparison with the results of this study. This way, the construction sector's contribution to Sustainable Development Goal 8.4 can be determined.

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