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An evaluation of decoupling in the Hungarian economy

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ABSTRACT: The paper examines the relationship between economic growth and greenhouse gas (GHG) emissions in Hungary from 1995 to 2022 using the Tapio decoupling model and the Mann-Kendall trend test. The Tapio decoupling elasticity coefficient (DI) was used to assess the relation between economic activity and environmental impact. The Mann-Kendall trend test was used to detect monotonic trends in Gross Value Added (GVA) and emissions, revealing their statistical significance and direction of change. The results revealed varying decoupling trends across various sectors. Strong decoupling occurred in sectors like B, C, D, and E, where emissions decreased alongside economic growth, reflecting technological advancements and structural shifts. Weak decoupling was observed in sectors such as A, F, G, and Q, where emissions grew more slowly than GVA, indicating progress but falling short of full decoupling. Conversely, sector T exhibited expansive negative decoupling, revealing unsustainable growth. At the national level, data from recent years have shown a trend toward absolute decoupling, in which GVA grew as emissions stabilized or declined. The Mann-Kendall test confirmed consistent economic growth across all sectors but diverse emission trends. Sectors like B and E achieved significant reductions in emissions, while others, including A and T, recorded increases. Some sectors, like I and M, displayed no clear trends, influenced by external or sector-specific factors.

KEYWORDS: GVA, GHG, trends, Tapio’s decoupling coefficient, sectoral analysis, Hungary
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1. Introduction and literature review

Decoupling could offer a solution to the dilemma of green growth (or ecologically sustainable economic growth). If economic performance becomes less dependent on material and energy consumption, and generates less waste and pollution, then theoretically, the economy could continue to grow without reaching ecological limits. Different types of decoupling can be distinguished based on whether we examine resource use in the economy (resource decoupling) or the impact of environmental pollutants at the other end of the economic process (impact decoupling) (Vadén et al. 2020a). It is important to highlight that these two types of decoupling can be entirely independent. In other words, decoupling from environmental impact can occur without decoupling from resource use, and vice versa (Jackson 2009; Sanyé-Mengual et al. 2019; Vadén et al. 2020a). The two most common methods for determining the relationship between environmental impact and economic growth are the Tapio decoupling method and the Environmental Kuznets Curve (EKC). Both have their own characteristics, but the Tapio model is more widely accepted and has attracted fewer criticisms.

The Tapio decoupling method offers several advantages over the EKC hypothesis for analyzing the relationship between economic growth and environmental pollution. While the EKC suggests a long-term pattern in which environmental degradation first increases and then decreases after reaching a certain income level, the Tapio method offers a more precise and flexible approach. It categorizes the relationship into distinct types of decoupling, enabling analysis of sectors such as energy and transportation, and how they contribute to decoupling at different stages of development. This method enables real-time monitoring and more targeted policies for addressing specific environmental issues as they arise, rather than waiting for a general turning point in economic growth (Chen – Wang 2024). Furthermore, the Tapio method is applicable to a wide range of environmental indicators beyond CO_2 emissions, including resource use, water consumption, and waste production. This makes it more versatile and comprehensive, allowing for a deeper understanding of environmental impacts across different sectors. It is also more relevant to both developed and developing countries, as it recognizes that decoupling does not occur automatically with income growth but requires active policy intervention. In contrast, the EKC provides less detailed guidance for policymakers and assumes that environmental improvements will eventually happen as economies grow, which may not be realistic for all regions (Tapio 2005; Stern 2017).

The methodology, which specifically examines the relationship between GDP and CO_2 emissions, was developed by Tapio (2005). It is now widely used because it requires little data, is easy to calculate, and can be applied across various economic sectors and spatial scales. Tapio's calculation method distinguishes between eight different types of decoupling and non-decoupling (see Figure 1). Its drawback, however, is the excessive number of decoupling types, with small differences between them, making it difficult to differentiate similar ones (Wu et al. 2018; Wang – Su 2020).

To illustrate, different decoupling trends may appear similar at first glance, even though their actual effects differ significantly. This is the case, for instance, when comparing weak and strong decoupling. In the case of weak decoupling, GDP continues to increase while environmental pressures also rise, but at a slower rate. In contrast, strong decoupling occurs when environmental impacts decrease while GDP keeps growing (Vadén et al. 2020a).

This distinction is crucial, as strong decoupling represents a genuine separation between economic growth and environmental degradation, creating the foundation for sustainable development. In the case of weak decoupling, environmental pressures are reduced only slightly, and by a degree that is insufficient to ensure a stable and sustainable future. Because emissions and environmental impacts continue to rise under weak decoupling, the apparent independence between growth and environmental load is deceptive, and climate targets as well as sustainable emission trends become increasingly difficult to achieve (Wang – Su 2020; Vadén et al. 2020a).

Weak decoupling is driven by temporary factors that cause short-term changes in emission trends, such as a sudden drop in energy prices or efficiency gains from the rapid spread of technological innovation. Unfortunately, such improvements are not sustainable in the long term; they merely delay the inevitable. These changes could also lead to a rebound effect in the long term, in which lower energy costs result in increased consumption (Wiedenhofer et al. 2020a). Moreover, decoupling is often examined at the level of specific regions or economic sectors, which can lead to more nuanced results. Even if adequate levels of decoupling are achieved within these limited scopes, global trends may still show continued growth in environmental pressures.

There are also some concepts, such as *degrowth,* that challenge the traditional assumption that continuous economic expansion equates to progress or prosperity (Jackson 2009). This questions the moral and ecological legitimacy of an economic model based on perpetual growth, highlighting the social and environmental costs of overproduction and overconsumption. From this perspective, sustained economic growth is neither ecologically viable nor socially just, particularly in highly developed societies. Instead, degrowth advocates for a strategic downscaling of production and consumption to reduce pressure on natural systems and foster a more balanced relationship between humans and the environment. This paradigm promotes the reorientation of societal values, prioritizing well-being, social equity, and ecological stability over material accumulation and profit maximization (Jackson 2009; Karagjozi 2025).

As Tim Jackson argues in *Prosperity Without Growth* (2009), genuine prosperity should be understood not through the lens of increasing GDP, but in relation to enhancing human and ecological well-being. His framework envisions an economy that operates within planetary boundaries, emphasizing quality of life, social cohesion, and sustainability as the true measures of progress (Karagjozi 2025).

Despite questions about degrowth and the importance of applying the method correctly, the Tapio model is widely accepted and less controversial, as it offers a more nuanced understanding of the relationship between economic growth and environmental impact. This method provides a clearer and more flexible approach to measuring decoupling at different stages of development. One of the key critiques of the EKC is its reliance on the assumption that economic growth alone will lead to environmental improvements, which overlooks persistent fossil fuel dependency and the slow adoption of low-carbon technologies. A literature review by Leal and Marques (2022) examines 200 articles, highlighting the limitations and questioning the reliance on the EKC. Globalization complicates decoupling under EKC, as developed countries may outsource emission-intensive industries and their associated environmental burden to developing nations. The relocation of polluting industries could lead to outcomes that do not align with predictions (Leal – Marques 2022). This means EKC might be considered an environmental performance indicator for policy design and implementation, but as a reference and not as a decisive indicator by itself (Stern 2017; Leal – Marques 2022). By choosing the Tapio method, the dynamic interaction between economic growth and environmental impact can be analyzed more effectively without assuming automatic improvements as income rises. It also allows for a more accurate assessment of national and global emissions, providing a clearer picture of how decoupling can be achieved (Stern 2017; Tapio 2005; Chen – Wang 2024). Tapio (2005) was the first to use the environmental measure he developed, initially for measuring traffic. Since then, it has been shown to work in other areas as well; it is widely accessible, easy to use, and yields representative results. The attributes demonstrate the scientific approach and application of decoupling. Unlike EKC, this method does not legitimize unchecked environmental impact; instead, with the appropriate parameters, it offers a comprehensive view of the relationship between current environmental and economic conditions.

1.1. Analyses and results of various authors

It seems useful, therefore, to present research that has focused on the decoupling method, which has been widely used to achieve scientifically substantiated, representative results. In recent years, several comprehensive reviews have been published, providing detailed summaries of the global status of decoupling economic growth from environmental impact. Wiedenhofer et al. (2020) conducted a systematic literature review focused on the use of natural resources and greenhouse gases. Similarly, Vadén et al. (2020a) conducted a systematic literature review, with ecological sustainability in general as a primary consideration. Wang and Su (2020), building on their own research focused specifically on CO_2 decoupling, produced a global overview on the topic. By comparing the results of these articles, we can obtain a more comprehensive, global perspective on CO_2 decoupling.

Wiedenhofer et al. (2020) and Haberl et al. (2020) examined evidence on the decoupling of GDP, resource use, and GHG emissions from 1970 to 2019. The aim of the screening process was to retain studies that were at least at the nation-state level, covered multiple sectors, and were quantitative, empirical studies on resource and impact decoupling. Ultimately, 835 studies remained. About 52% of these studies were published between June 2014 and June 2019, and approximately 42% dealt with greenhouse gases. Across the 835 studies, 1,152 analyses were conducted, 34% (389 analyses) of which specifically addressed CO_2 emissions from the combustion of fossil fuels. Since 1970, a continuous decline in the growth rate of global CO_2 emissions has been observed. According to empirical research, between 1970 and 2014, global GDP grew by an average of 3.5% per year, while growth in global CO_2 emissions averaged 2.5% per year, indicating relative decoupling during this period. Between 2000 and 2014, a higher rate of CO_2 emissions growth (2.8% per year) was observed. Evidence of relative decoupling was found in data from many countries worldwide. The review found that approximately two dozen countries, predominantly in Europe, witnessed declining CO_2 emissions alongside growing GDP, in most cases both in terms of consumption and production (Le Quéré et al. 2019; Haberl et al. 2020).

In their literature review, Vadén et al. (2020a) focused primarily on studies demonstrating resource and impact decoupling, as well as absolute and relative decoupling. The screening process retained studies that specifically examined decoupling within the framework of ecological sustainability and clearly differentiated between resource and impact decoupling and absolute and relative decoupling. They looked for studies covering larger geographical areas, spanning multiple sectors, and ideally covering longer time periods, with publications from 1990 to 2019. Ultimately, they reviewed 179 studies. Across these 179 studies, 170 instances of relative decoupling, 97 instances of absolute decoupling, and 8 instances in which no decoupling was found were identified. Among these, 50 studies were conducted at the international level and 7 at the global level. In total, 116 studies examined the economy. Of the 97 studies demonstrating absolute decoupling, 74 involved impact decoupling. Six studies addressed the decoupling of greenhouse gases in general, while 50 studies focused specifically on CO_2. In the eight studies where no decoupling was found, the research was limited to specific geographical areas (India, Turkey, ASEAN countries, China, Switzerland) (Vadén et al. 2020a; 2020b).

Wang and Su (2020) conducted an empirical study on global decoupling. They examined decoupling across 192 countries from 2000 to 2014. The countries were divided into nine groups. They separately analyzed five countries with exceptionally high CO_2 emissions globally during the study period (China, the USA, Russia, India, Japan). Additionally, they looked at Europe and groups of countries labelled D1, D2, and D3.[3] Their main questions were whether there is decoupling between economic growth measured by GDP and CO_2 emissions, what drives it, if it exists, and how it can be made more effective. To examine decoupling trends, Wang and Su (2020) applied the T-LMDI method, an advanced version of the Tapio method. Global CO_2 emissions continued to rise during the study period (2000-2014). Although the economic crisis of 2008-2009 caused emissions to decline for those two years, global CO_2 emissions still grew by an average of 2.58% annually from 2000 to 2014 (Wang – Su 2020). Due to the high specific energy demand of peripheral countries, decoupling was less common or non-existent among them. In their analysis, Wang and Su (2020) found absolute decoupling in European countries within the core regions, while relative decoupling was predominant in other core groups (USA, D1), trending towards absolute decoupling. The 2008-2009 crisis led to expansive negative decoupling, followed by recessive decoupling, before absolute decoupling was restored in the core countries in 2013. For Japan, no specific decoupling pattern was observed, as it was already fluctuating between different patterns, a trend worsened by the crisis. Peripheral countries (D2, D3, India, China) displayed mixed decoupling patterns, with, at best, only relative decoupling. They exhibited chaotic decoupling patterns, including relative negative, expansive negative, relative, and absolute decoupling, as well as expansive coupling. Although relative decoupling was observed for more than half of the period (D2), it was unstable, frequently alternating between the patterns listed above. In some countries, neither absolute nor relative decoupling was found. These peripheral countries (D3) were in the early phases of economic growth, with high specific energy demand needed for further growth, resulting in high CO_2 emissions (Wang – Su 2020).

Rodríguez et al. (2018) examined the relationship between GDP per capita and CO_2 emissions per capita across the EU-28 Member States from 1950 to 2012. The studies showed that in the EU-15 countries, active decoupling is

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[3] For the research, countries were categorized for the research based on the following parameters: D1, non-highlighted core countries; D2, peripheral countries; and D3, outer peripheral countries (Wang – Su 2020).

taking place in some form. When considering all 28 countries, it can be observed that in some countries, the absolute decoupling trend remains consistent (Sweden, Finland, Poland – except for a few years – and from 1970, Ireland as well). Several other countries (including Hungary) also achieved absolute decoupling during a part of the study period, but could not maintain it throughout. Furthermore, some countries with different decoupling trends were grouped together because they faced similar challenges in decoupling (Southern and Eastern European countries belong to this group). The study also identified countries that have completely decoupled from CO_2 emissions (Slovenia, Malta, Denmark). Cohen et al. (2018) examined the 20 largest CO_2 emitters, which are responsible for 74% of global anthropogenic emissions. In their study, they focused on the period 1990-2014, but for 13 of those countries, emission data dating back to the 1850s were available, which helped facilitate a comprehensive analysis of trends. According to their research, relative decoupling was observed in the European countries under study, but in six countries (Italy, Russia, Ukraine, France, Germany, and the United Kingdom), absolute decoupling was also likely. These are partly the countries that were the first to implement international regulations to reduce CO_2 emissions. Naqvi and Zwickl (2017) examined the OECD decoupling factors modified by the Tapio method using data from the Eurostat and WIOD (World Input-Output Database) between 1995 and 2008 for 18 European Union Member States. To determine the direction of the decoupling trend, they divided the study period into two parts (1995-2001; 2001-2008). The authors studied six different pollutants, including CO_2, across six different economic sectors. Over the entire study period, CO_2 emissions increased in the electricity generation, transportation, and services sectors, but decreased in the other sectors.

In terms of CO_2 emissions, Naqvi and Zwickl (2017) found that 14 of the 18 countries had demonstrated absolute decoupling in one or more (but no more than four) sectors. In the other sectors, they found various types of decoupling alongside absolute decoupling. For the remaining four countries (Spain, Greece, Ireland, and Portugal), no absolute decoupling was found in any sector. No complete, economy-wide CO_2 decoupling was observed. The authors noted that the decoupling patterns in the two periods under study were different. When comparing the two periods, no characteristic trend or direction was found. Furthermore, results achieved in the first period did not guarantee their persistence in the second period, nor did stricter regulations necessarily lead to success in the later period. According to the theory of green growth, absolute decoupling is key to achieving sustainable economic growth, with relative decoupling being only a transitional state. Despite this, Naqvi and Zwickl (2017) found one country that had already achieved absolute decoupling, only to demonstrate relative decoupling values in the second study period: Poland (Naqvi – Zwickl 2017).

Mikayilov et al. (2018) examined the relationship between GDP per capita and CO_2 emissions per capita across 12 European countries from 1861 to 2015. This choice of a long time span is advantageous because short periods with extreme values can distort the results. They found relative decoupling between the two variables in eight countries, while of the 12 countries studied, significant variability in the relationship between GDP per capita and CO_2 emissions per capita was observed, and this was true for all but three countries (England, Belgium, and the Netherlands), a fact largely attributed to the two World Wars and the subsequent rapid economic growth. In four countries (Austria, Denmark, the Netherlands, and Switzerland), no decoupling was observed because CO_2 emissions are highly sensitive to changes in GDP.

2. Materials and methods

2.1. Dataset

For the calculations, the data was downloaded from the Hungarian Statistical Office's website on October 22, 2024. From this dataset, the necessary and relevant information was extracted covering the period between 1995 and 2022, which serves as the scope of the analysis in this paper. Greenhouse gas (GHG) emissions were measured in thousand tons of CO_2 equivalent, while GDP was assessed as gross value added (GVA) at current prices in millions of forints (HUF), broken down by economic sectors and years. CO_2 is naturally stored in various forms in the environment, such as in forests, where it poses no environmental threat. However, disturbing these carbon sinks can release significant amounts of greenhouse gases. In the analyses, aggregated CO_2-equivalent data focusing on net emissions (excluding sinks) were used. The data were processed using IBM SPSS software.

These data series were analyzed using two methods. First, the Tapio decoupling elasticity coefficient (DI) and, second, the Mann-Kendall trend test were used to determine whether true decoupling or diverging trends can be observed across various economic sectors in Hungary.

It is important to note that the analysis starts in 1995, as sufficient data have been available from the Hungarian Statistical Office database since this year. It may also be interesting to examine data starting from 1990, since this period is particularly relevant due to cooperation-related factors and the specific characteristics of the "transition" era in Central and Eastern Europe following the political changes of 1989-90.

2.2. Tapio methodology

The theory of the decoupling elasticity coefficient (DI) was first proposed by Tapio (2005) and, since then, has been widely used to demonstrate the disconnect between environmental pollution and economic growth. In the present research, this model is used to explore the relationship between the economic growth of the Hungarian national economy's different sectors (NACE Rev. 2., 2008)[4] and their greenhouse gas (GHG) emissions. *DI* (Eq. 1) can be estimated as the ratio of change in GHG emission (%ΔC) to the change in an economic indicator (%ΔG) (in the present study, gross value added, GVA) (Tang et al. 2014; Hu et al. 2017).

$$DI = \frac{\%\Delta \mathrm{C}}{\%\Delta \mathrm{G}} \tag{1}$$

%ΔC is computed as in (Eq. 2) and %ΔG as given in (Eq. 3):

$$\%\Delta C = \frac{(C_t - C_b)}{C_b} \tag{2}$$

$$\%\Delta G = \frac{(G_t - G_b)}{G_b} \tag{3}$$

where C_t is the GHG emission of the current period, C_b is the GHG emission of the base period, G_t is the GVA of the current period and G_b is the GVA of the base period.

According to the grade classification of decoupling suggested by Tapio (2005) (Hu et al. 2017; Li et al. 2021), the categories listed in *Figure 1* were used. The favorabledecoupling categories are recession decoupling, weak decoupling, and, the best from an environmental perspective, strong decoupling.

To understand decoupling correctly, it is essential to have a comprehensive overview of its types. These are illustrated in *Figure 1*. We must distinguish between the concepts of absolute and relative decoupling, as well as expansive negative and recessive decoupling. Absolute decoupling occurs when economic performance increases while environmental impact remains unchanged. This is also referred to as strong decoupling (Tapio 2005). Relative decoupling occurs when economic growth outpaces the increase in environmental impact, although the latter still rises. This is also referred to as weak decoupling (Tapio 2005; Sanyé-Mengual et al. 2019; Vadén et al. 2020a; Frodyma et al. 2020).

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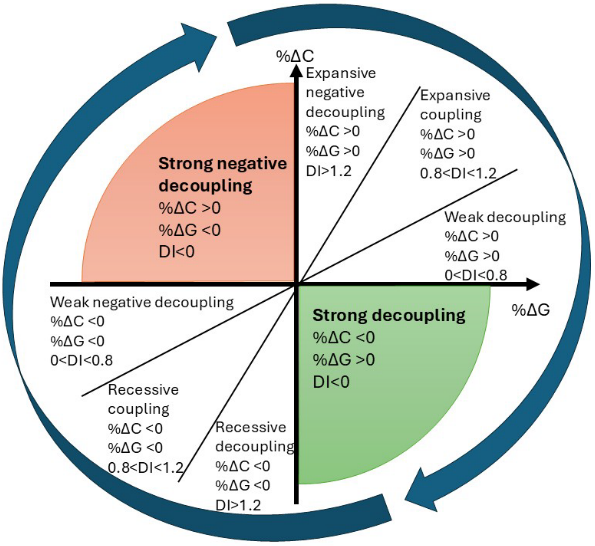
[4] NACE Rev. 2 (2008) is the European Union's statistical classification system for economic activities, developed by Eurostat (2008). It organizes economic activities into hierarchical categories (sections, divisions, groups, and classes) for comparability across the EU (Eurostat 2008).

When DI < 0, this indicates an absolute decoupling state, in which economic growth is achieved while reducing carbon emissions. This can happen in the cases of strong decoupling or strong negative decoupling (*Figure 1*). When 0 ≤ DI < 0.8, this indicates relative decoupling, where the economy grows faster than carbon emissions, but emissions still increase (weak decoupling and weak negative decoupling). When 0.8 ≤ DI ≤ 1.2, this reflects a coupling or weak decoupling state, where economic growth and carbon emissions increase at similar rates (expansive coupling, recessive coupling). When DI > 1.2, this represents negative decoupling, where carbon emissions increase faster than economic growth, which is undesirable (expansive negative decoupling, recessive decoupling) (Jing et al. 2024). Expansive negative decoupling refers to a scenario in which both economic performance and environmental impact increase, but the latter rises to a much greater extent (Tapio 2005; Wang – Su 2020). Recessive decoupling occurs when the economy does not grow, and environmental impact decreases simultaneously (Tapio 2005). The types of decoupling are summarized in *Figure 1.*

Figure 1. Schematic diagram of decoupling states



Source: authors, based on Dahmani et al., (2021) and Li and Jiang (2017)
Note: %ΔC is the change in GHG emission, %ΔG is the change in the economic indicator, and DI is the Decoupling Index.

The extent of decoupling is influenced by three main factors: the size of the area under study (as well as its location and geological characteristics), the number of economic sectors included in the analysis, and the temporal scale of the investigation (Vadén et al. 2020b; Wiedenhofer et al. 2020). In empirical research, decoupling can be examined across different spatial scales, from local to global. Decoupling is easier to interpret at smaller scales, as the broader context is typically disregarded. However, this smaller-scale analysis can be misleading, as external factors not considered in the study still affect the area. Consequently, the results may not reflect accurate values. Researchers often overlook global effects (Jackson 2009; Vadén et al. 2020b). In examining decoupling, we can consider one or multiple economic sectors or even extend our analysis to the entire economy. The issue with studies based on one or just a few sectors is that they do not account for the relationships between the sector in question and other sectors. For instance, if there is a sudden decrease in energy consumption in one sector, it may impact several other economic sectors, leading to an increase in their consumption (rebound effect). This can be avoided by comprehensively analyzing economic sectors and their interactions (Vadén et al. 2020a).

To examine decoupling, a decoupling trend is necessary. This trend allows us to observe actual increases or decreases, even at the forecast level. Over shorter timescales, variables that fluctuate within smaller time frames can distort results, such as seasonal heating and cooling needs throughout the year or changes caused by a temporary economic crisis on slightly longer timescales. To avoid this variability, it is essential to separate the trend from fluctuating values. By appropriately analyzing the trend components over a suitable timescale, we gain a clearer understanding of the actual situation (Cohen et al. 2018; Mikayilov et al. 2018; Vadén et al. 2020b; Cohen et al. 2022).

2.3. Mann-Kendall trend test

The Mann-Kendall trend test is widely used to find trends in time series data. It was first introduced by Mann (1945) and later developed further by Kendall (1975). This test checks whether a dataset exhibits a monotonic trend over time, without requiring the data to follow a specific distribution.

The theoretical background is presented, with a focus on the study by Kocsis et al. (2020). To determine the presence of a monotonic trend in a time series, the null hypothesis (H0) of the Mann-Kendall test is that there is no monotonic trend in the series. The alternative hypothesis (Ha) is that the data follow a monotonic trend over time. The Mann-Kendall test statistic is given as (Eq. 4):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \tag{4}$$

where $j > k$ and
k=1,2,..., n-1
j=2,3,..., n

and *n* is the number of data. *Sgn* $(x_j - x_k)$ is calculated as follows (Eq. 5):

$$sgn(x_j - x_k) = \begin{cases} +1 \ \ if \ \ x_j - x_k > 0 \\ \ \ 0 \ \ if \ \ x_j - x_k = 0 \\ -1 \ \ if \ \ x_j - x_k < 0 \end{cases} \tag{5}$$

Kendall (1975) proved that *S* is asymptotically normally distributed with the following parameters (Eq. 6):

$$E(S) = 0$$

$$Var(S) = \left\{n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5)\right\}/18 \tag{6}$$

where
g is the number of tied groups in the data set,
t_p is the number of data in the p^{th} tied group,
n is the number of data points in the time series.

A positive value for *S* indicates an increasing trend; a negative value indicates the opposite, i.e., a decreasing trend over time. For *n* > 10, e.g., more than ten observations, a standard normal random variable, *Z*, can be used in the hypothesis test (Eq. 7):

$$Z = \begin{cases} \frac{S-1}{[Var(S)]^{1/2}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{[Var(S)]^{1/2}} & if \quad S < 0 \end{cases} \tag{7}$$

S is closely related to Kendall's rank correlation coefficient (τ); therefore, testing τ is equivalent to testing *S* (Eq. 8):

$$\tau = \frac{S}{D} \tag{8}$$

where *D* is the possible number of observation pairs from a total of *n* observations (Eq. 9).

$$D = \binom{n}{2} \tag{9}$$

During the hypothesis test, a significance level of α=5% was used in a two-tailed test, in which the null-hypothesis is that there is no monotonic trend in the time series (H_0: τ = 0), and the alternative hypothesis is that there is a significant monotonic trend in the time series (H_a: τ ≠ 0).

By analyzing trends, small changes in emission patterns can be revealed, even when the data exhibit seasonal or recurring variations (Gutiérrez-Hernández – García 2024). Studies over the last two decades have shown how this method helps understand the effects of climate policies and energy transitions on emissions and economic growth (IEA 2024; NCAR 2014).

In this research, the Mann-Kendall trend test is applied to evaluate tendencies in GHG emissions and GVA time series in Hungary's economic sectors, with the goal of identifying potential decoupling patterns. By detecting monotonic trends, this method helps determine whether a significant shift toward decoupling can be observed over time. Many countries aim to grow their economies while reducing emissions through new technologies and policies, and the Mann-Kendall test offers a robust approach to determining whether such trends are indeed present and, if so, assessing their strength. Its capacity for analyzing complex data relationships makes it an ideal tool for understanding the links between emissions and economic growth (IEA 2024; NCAR 2014). The Mann-Kendall trend test is often used for analyzing hydrological time series and has been widely applied in environmental studies, though its use in the field of economics to carry out trend analysis of this kind is novel. It also has modified versions for seasonal and autocorrelated time series. The limitation of the Mann-Kendall test is that, while it can determine the presence or absence of a monotonic trend over the time frame under analysis, it cannot account for breakpoints, a limitation common to the regression over time method as well.

3. Results

3.1. Tapio decoupling elasticity coefficient (DI)

The analysis of decoupling trends between GVA and GHG emissions from 1995 to 2022 is presented in *Table 1*, based on the Tapio model.

Table 1. Decoupling index (DI) calculation table

Decoupling index calculation			
National economy sectors	**%ΔG**	**%ΔC**	**DI**
A	3.862	0.102	0.026
B	11.977	-0.671	-0.056
C	9.494	-0.374	-0.039
D	4.426	-0.421	-0.095
E	6.876	-0.119	-0.019
F	13.610	2.444	0.179
G	12.762	2.423	0.189
H	8.994	0.656	0.072
I	9.013	0.283	0.031
J	15.636	-0.003	-0.0002
K	8.266	-0.466	-0.056
L	17.499	0.055	0.003
M	18.514	0.144	0.007
N	18.683	4.214	0.225
O	9.351	-0.190	-0.020
P	7.629	-0.592	-0.077
Q	10.260	0.034	0.003
R	9.257	-0.316	-0.034
S	4.674	-0.252	-0.054
T	11.624	814.634	70.081
Economy	10.340	-0.17389	-0.01682

Source: authors

The results reveal that most sectors demonstrate a form of decoupling, but the degree varies across sectors. The sectors can be divided into three categories: those with weak decoupling, strong decoupling, and expansive negative decoupling. Weak decoupling is observed in sectors such as A, F, G, H, I, L, M, N, and Q,[5] where economic growth continues but GHG emissions also increase, though

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[5] See the names of the national economy sectors corresponding to the letters of each sector in *Appendix 1.*

at a slower rate. These sectors are moving towards a form of decoupling, where emissions growth is outpaced by economic growth, but it is not yet fully realized.

In contrast, strong decoupling is evident in sectors such as B, C, D, E, J, K, O, P, R, and S. These sectors exhibit reductions in GHG emissions while still experiencing positive economic growth. The ability of these sectors to reduce emissions despite economic expansion suggests that they have successfully implemented measures such as improved energy efficiency, cleaner technologies, or structural shifts in economic activities that reduce environmental impact. This type of decoupling indicates significant progress in aligning economic and environmental goals.

The most extreme case of decoupling is found in sector T, where expansive negative decoupling occurs. This sector displays a sharp increase in GVA, but GHG emissions rise even more drastically, resulting in a very high DI value. The expansive negative decoupling in sector T indicates that while the economic output of the sector has expanded, its environmental impact has escalated at a much greater rate. This suggests that the growth in this sector has not been sustainable from an environmental perspective.

The overall decoupling trend across the economy shows a tendency toward absolute decoupling. The economy demonstrates that economic growth has been achieved while GHG emissions have either decreased or remained stable in recent years. However, this decoupling has not been uniform across all sectors, as some continue to experience growth in both GVA and emissions, while others have succeeded in reducing their environmental impact alongside economic expansion. The decoupling elasticity coefficient (DI) for the entire economy reflects a mixed pattern of success, with some sectors leading the way in decoupling, while others require more targeted interventions to achieve sustainable growth.

3.2. Tendencies of the GHG and GVA time series based on the Mann-Kendall trend test

In this section the focus is on identifying significant trends across national economy sectors, as well as within the sectors themselves, over the period from 1995 to 2022. The values for both GVA (*Table 2*) and GHG emissions (*Table 3*) are presented in the following tables. The empirical significance level (p-value) was determined to evaluate the tendencies.

Table 2. Kendall's τ of the GVA time series

National economy sectors	Correlation coefficient (τ)	p-value
A	0.905	<0.001*
B	0.804	<0.001*
C	0.979	<0.001*
D	0.730	<0.001*
E	0.915	<0.001*
F	0.825	<0.001*
G	0.963	<0.001*
H	0.984	<0.001*
I	0.847	<0.001*
J	0.989	<0.001*
K	0.905	<0.001*
L	0.984	<0.001*
M	0.989	<0.001*
N	0.974	<0.001*
O	0.958	<0.001*
P	0.862	<0.001*
Q	0.984	<0.001*
R	0.942	<0.001*
S	0.947	<0.001*
T	0.834	<0.001*
GVA	0.989	<0.001*

Note: * denotes significance at the 5% significance level.
Source: authors

The Mann-Kendall trend test results reveal significant, positive monotonic trends in GVA across all national economy sectors at the 5% significance level. This is evident from the p-values, all of which are below 0.001, and the positive Kendall's tau correlation coefficients. The results indicate that GVA has consistently increased over the observed period, with no sector showing a decline or non-significant trend.

Table 3. Kendall's τ of the GHG time series

National economy sectors	Correlation coefficient (τ)	p-value
A	0.365	0.006*
B	-0.831	<0.001*
C	-0.492	<0.001*
D	-0.778	<0.001*
E	-0.513	<0.001*
F	0.857	<0.001*
G	0.836	<0.001*
H	0.286	0.033*
I	**0.164**	**0.221**
J	-0.344	0.01*
K	-0.571	<0.001*
L	-0.328	0.014*
M	**-0.069**	**0.607**
N	0.889	<0.001*
O	**-0.074**	**0.58**
P	-0.709	<0.001*
Q	-0.423	0.002*
R	-0.444	<0.001*
S	-0.444	<0.001*
T	0.819	<0.001*
GHG	-0.619	<0.001*

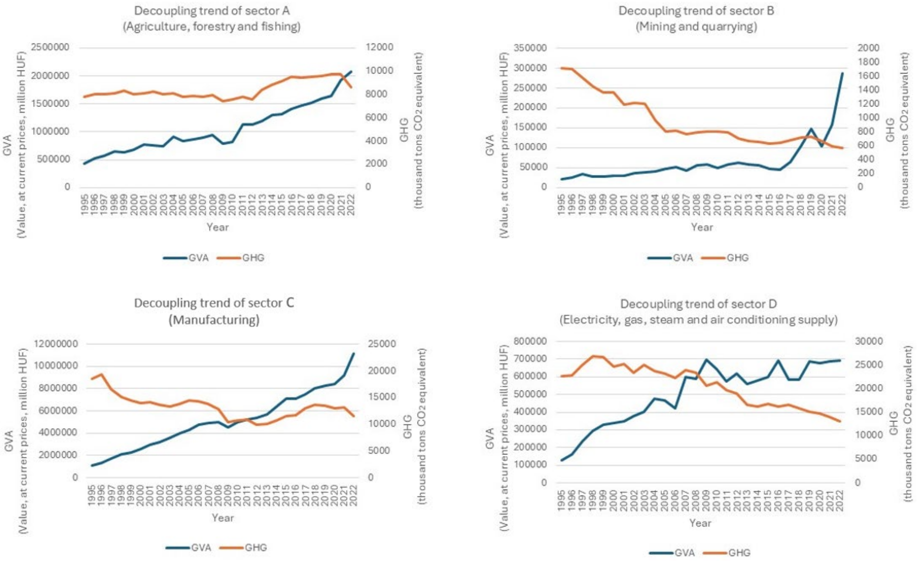
Note: * denotes significance at the 5% significance level; non-significant trends are highlighted in bold.
Source: authors

The analysis of GHG emissions across national economy sectors reveals significant monotonic trends in most cases, with p-values indicating statistical significance at the 5% level. There are some exceptions, however, where no significant trends were observed. The results show that while many sectors experience increasing or decreasing emissions, certain sectors exhibit no clear tendency in GHG emissions.

In sectors A, F, G, H, N, and T, an increasing trend in emissions is observed, indicating that emissions continue to rise in these sectors. These trends are statistically significant, suggesting that the economic activities in these sectors are associated with increasing GHG emissions over time. On the other hand, in sectors B, C, D, E, J, K, L, P, Q, R, and S, emissions are decreasing. This suggests that emissions in these sectors are declining, which may reflect efforts to reduce environmental impact or improvements in energy efficiency, though the underlying causes warrant further exploration.

Despite the overall significance of the trends in many sectors, not all sectors exhibit a clear tendency. Specifically, sectors I, M, and O (marked in bold in *Table 3*) show no significant trend, indicating that their GHG emissions do not change statistically significantly over time based on the Mann-Kendall test. *Figures 2* to 6 display the yearly GVA and GHG values for the various sectors of the national economy between 1995 and 2022.

Figure 2. Pattern of GVA and GHG values in the national economy sectors A-D


Decoupling trend of sector A (Agriculture, forestry and fishing)

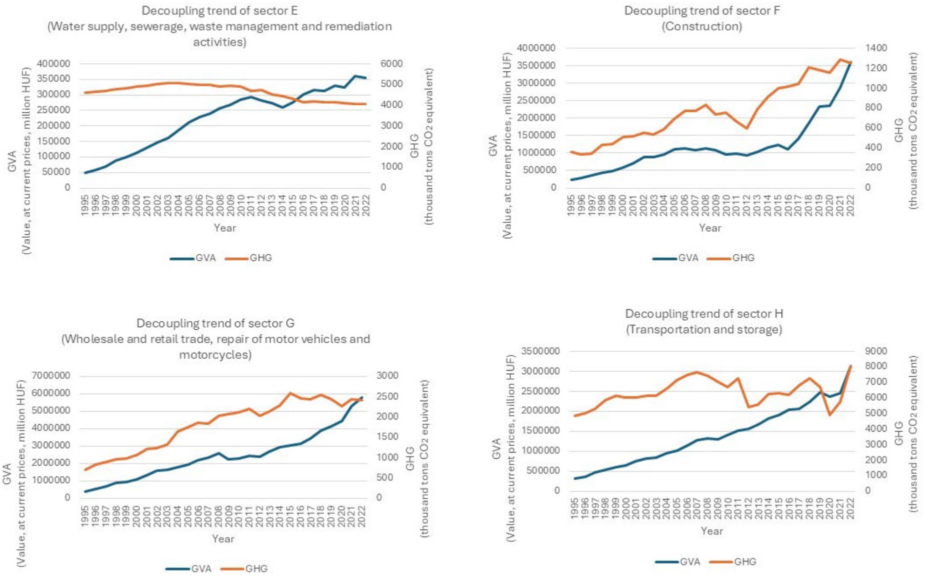
Decoupling trend of sector B (Mining and quarrying)

Decoupling trend of sector C (Manufacturing)

Decoupling trend of sector D (Electricity, gas, steam and air conditioning supply)

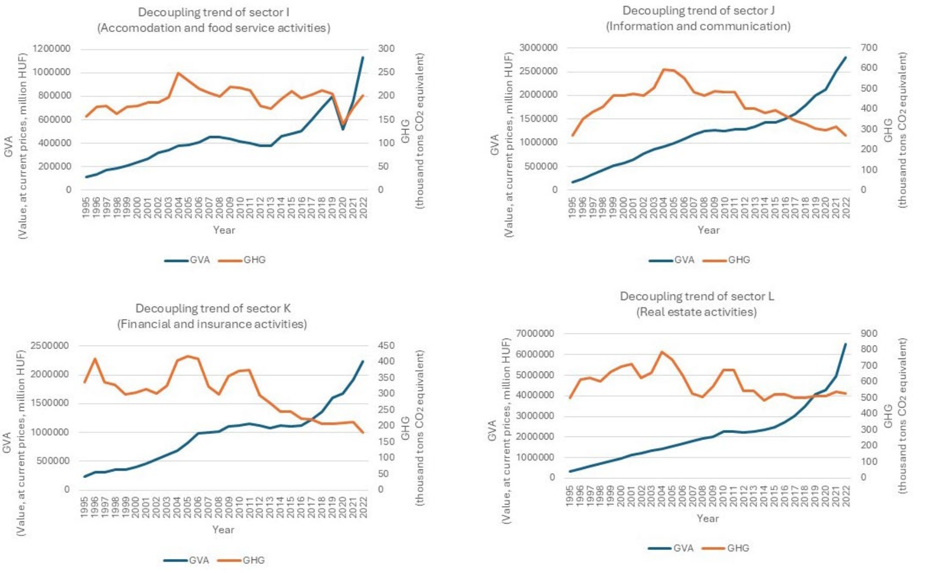
Source: authors

Figure 3. Pattern of GVA and GHG values in the national economy sectors E-H



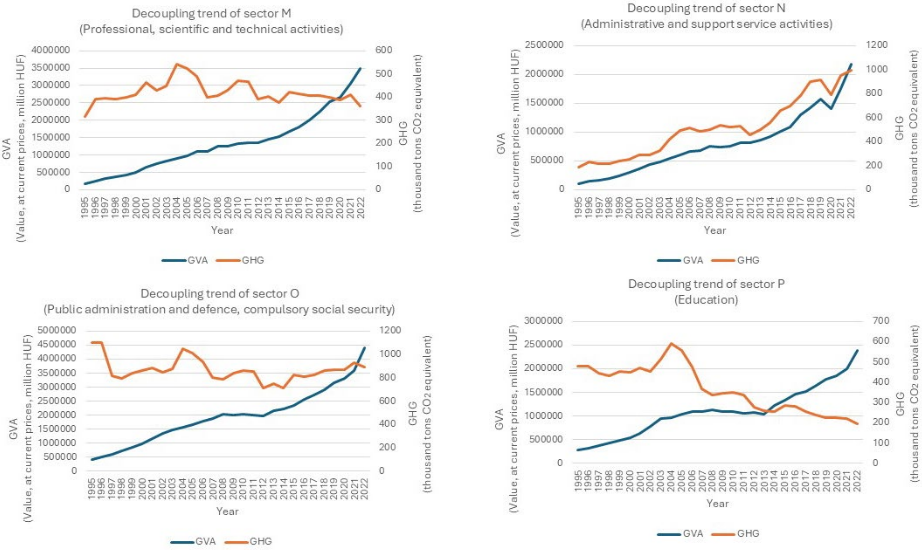
Source: authors

Figure 4. Pattern of GVA and GHG values in the national economy sectors I-L



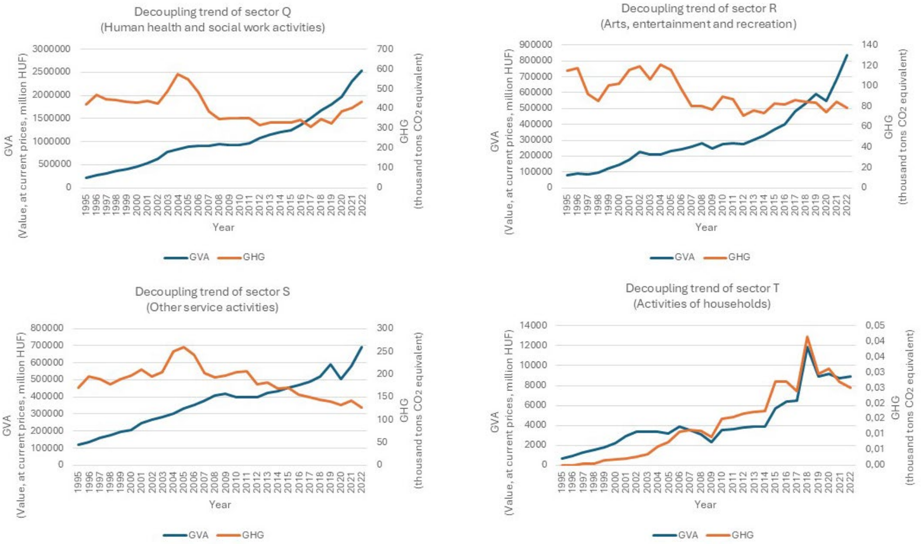
Source: authors

Figure 5. Pattern of GVA and GHG values in the national economy sectors M-P



Source: authors

Figure 6. Pattern of GVA and GHG values in the national economy sectors Q-T



Source: authors

4. Discussion

The analysis of decoupling trends between GVA and GHG emissions in Hungary from 1995 to 2022 reveals varied patterns across national economic sectors, with different degrees of decoupling observed. The decoupling elasticity coefficient (DI), based on the Tapio model (Tapio 2005; Li – Jiang 2017), highlights a complex relationship between economic growth and environmental impact. The findings categorize the decoupling trends into three broad categories: weak decoupling, strong decoupling, and expansive negative decoupling (Vadén et al. 2020a). These trends suggest that while many sectors have managed to reduce their GHG emissions while continuing economic expansion, some sectors have failed to achieve this balance, indicating a need for more targeted interventions. Overall, the national economy demonstrates a mixed pattern of success in decoupling, in which some sectors show significant progress while others continue to exhibit unsustainable growth.

Many sectors in the analysis show weak decoupling, which refers to a scenario where economic growth outpaces emissions growth, but the decoupling effect is not yet fully realized (Vadén et al. 2020a). Sectors such as A, F, G, H, I, L, M, N, and Q display this trend, as can be seen in *Figures 2 to 6*, where GHG emissions continue to rise, but at a slower rate than economic activity. This suggests that while these sectors are making some progress in reducing the environmental impact of their economic growth, they still face challenges in achieving full decoupling. These trends can be attributed to various factors, including technological advances, changes in production processes, and improvements in energy efficiency, but these sectors need further efforts to achieve more substantial emissions reductions (Daly – Farley 2018).

Conversely, the sectors demonstrating strong decoupling, such as B, C, D, E, J, K, O, P, R, and S, show a more favorable outcome: GHG emissions decline while GVA continues to increase. This suggests that these sectors have successfully implemented more effective measures to reduce environmental impacts even as they experience economic growth (Vadén et al. 2020a). Strong decoupling is often associated with structural shifts in economic activities, such as the transition towards cleaner technologies, energy efficiency improvements, and a shift towards less carbon-intensive industries (Wiedenhofer et al. 2020).

In the extreme case, sector T exhibits expansive negative decoupling, where GVA increases sharply, while GHG emissions rise even more dramatically. This indicates a scenario where the growth of the sector is not environmentally sustainable, as emissions increase at a much faster rate than economic output. Expansive negative decoupling suggests that while economic activity is growing rapidly, it is accompanied by a significant rise in environmental cost (Wang – Su 2020). This could be due to sectors that are heavily dependent on resource-intensive processes, such as fossil fuel extraction, heavy industry, or other sectors with high environmental impacts. Addressing this trend would require significant policy interventions aimed at reducing emissions through cleaner technologies or shifts towards more sustainable economic practices (Barbier 2011).

Within the European Union, the primary objective of energy policy is to promote sustainable economic growth while reducing greenhouse gas emissions. This principle underlies both the EU's energy efficiency initiatives and the National Energy and Climate Plans (NECPs) of the Member States. During the 2014–2020 period, EU-level energy efficiency programs achieved an estimated annual final energy saving of 3 to 4 Petajoules (PJ). However, to achieve the 2030 climate targets, the rate of new annual savings must approximately double to around 7 PJ per year (MEKH 2025). In line with this, Hungary's revised NECP raised its cumulative energy savings target for 2021–2030 from 336.5 PJ to 484.6 PJ — an increase of 44% (MEKH 2025). This expansion is supported by progressively stricter efficiency requirements, with annual savings expected to rise to between 9.9 and 14.5 PJ by the end of the decade (MEKH 2025).

The updated Hungarian plan also increased the national renewable energy target from 21% to 30% of total energy consumption by 2030 (Government of Hungary 2024). The decoupling of GDP growth from emissions is already evident in certain sectors: while economic output has increased, emissions have declined due to efficiency improvements and the expansion of renewable energy. Geothermal energy has gained importance in district heating systems,[6] where its share rose from 5.3% in 2018 to 8% in 2023 (Government of Hungary 2024).

At the EU level, the revised Renewable Energy Directive (2018/2001/EU) and the Governance Regulation (2018/1999/EU) provide the legal framework for this transition. According to the European Commission's assessment (COM (2020) 564 final), existing and planned measures could raise the EU's renewable share to between 33.1% and 33.7% by 2030, surpassing the official 32% target (ONA 2021a). The most significant renewable sources remain bioenergy, solar, and wind, with the latter two technologies growing from a combined capacity of 110 GW in 2010 to 261 GW in 2018 — a clear indicator of structural decoupling between energy demand and carbon intensity (ONA 2016; ONA 2021a).

Hungary has also strengthened its renewable electricity generation through the so-called *METÁR* renewable support scheme, launched in 2019, which attracted substantial investment interest. These developments demonstrate both the EU's and Hungary's commitment to achieving economic growth alongside a gradual reduction in carbon emissions (ONA 2016; ONA 2021a).

The overall decoupling trend in the national economy suggests a general tendency towards absolute decoupling, where economic growth is increas-

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[6] A district heating system is a network that distributes heat that is generated in a centralized location.

ingly decoupled from the growth of GHG emissions. The economy has managed to achieve economic growth while reducing emissions or stabilizing them in recent years. However, this trend is not uniform across all sectors, as some sectors have yet to achieve a balance between economic growth and emissions reduction. The mixed decoupling patterns suggest that while progress has been made, there is still room for improvement, especially in sectors where emissions continue to rise despite economic growth (Hickel 2020).

The Mann-Kendall trend test further reinforces these findings, revealing significant monotonic trends in GVA across all sectors, indicating consistency and growth. The results show that no sector experienced a decline in GVA, confirming the general upward trajectory of the economy over the period under consideration. However, when analyzing GHG emissions, the results reveal greater variability, as while many sectors show decreasing emissions, some sectors, such as A, F, G, H, N, and T, exhibit rising emissions, suggesting that economic growth in these areas is closely tied to increasing environmental impact. This highlights the need for more focused efforts to address emissions in specific sectors that are struggling to reduce their carbon footprint (Hickel 2020).

The lack of a significant relationship between emissions and time in certain sectors (such as I, M, and O) further complicates the decoupling analysis. In these sectors, the relationship between GHG emissions and economic growth remains unclear, with some sectors showing stable emissions while others displaying too much variability for clear patterns to emerge. This could be indicative of underlying factors influencing emissions in these sectors, such as regulatory changes, the adoption of new technologies, or external economic shocks that affect emissions in unpredictable ways (Wang – Su 2020). Further research into the specific dynamics of these sectors is needed to understand the factors that contribute to these non-significant trends.

While many sectors show promising trends toward decoupling economic growth from environmental degradation, substantial challenges remain, particularly in sectors with rising emissions. The overall decoupling index for Hungary's national economy indicates that while some sectors have made significant progress, others still face difficulties in achieving sustainable growth. The findings highlight the importance of continued efforts to reduce emissions in key sectors and the need for targeted policies and technologies to ensure that economic growth does not come at the cost of the environment.

Regarding one specific point, the activities of households (sector T) should be supported by interventions in energy efficiency, namely subsidies to households, as energy use is one of the main sources of GHG emissions in this sector. Environmental education is also a critical point in the formation of attitudes towards environmental protection and climate consciousness at an individual level.

5. Conclusions

A range of policy measures and incentives have been implemented to address greenhouse gas emissions and climate change. Among the most commonly used tools is the carbon tax, which penalizes businesses for emitting CO_2, thereby encouraging them to adopt cleaner practices. Subsidies for renewable energy technologies, such as wind, solar, and hydropower, are another key measure, as they help reduce the financial barriers to adopting these technologies. Additionally, the EU Emissions Trading System (ETS) provides a cap-and-trade mechanism where companies are allocated or can purchase emission allowances, creating a financial incentive to reduce emissions. Looking to the future, innovative solutions will be crucial for achieving climate goals. Incentives for green technology development, such as funding for the research and development (R&D) of carbon capture and storage or next-generation renewable energy systems, will be necessary. Stricter emission caps, implemented over time, can further drive the transition to a low-carbon economy. Policies that promote a circular economy, focusing on reducing waste and encouraging sustainable production and consumption, will also play a critical role. The success of these measures depends on collaboration across sectors. Governments, businesses, and civil society must work together to implement policies effectively. Public-private partnerships, in particular, can drive innovation and fund large-scale green initiatives. Deploying a combination of existing tools and forward-looking solutions is essential for addressing the challenges of climate change.

When addressing the challenges of energy use and greenhouse gas emissions, two complementary approaches stand out: increasing energy efficiency and reducing energy demand. Energy efficiency focuses on improving the output of energy-consuming processes without increasing the amount of energy used. For example, retrofitting buildings with better insulation and energy-efficient windows can significantly reduce heating and cooling needs. Upgrading lighting systems to LED technology is another effective way to lower electricity consumption. These measures ensure that energy is used more effectively, reducing waste and achieving the same level of comfort, productivity, or performance, but with less energy input. On the other hand, reducing energy demand involves encouraging behavioral and systemic changes to minimize overall energy consumption. For instance, promoting remote working and telecommuting reduces the need for the daily use of transportation, thereby lowering fuel consumption and emissions. Encouraging individuals to carpool or use public transportation can also significantly reduce energy demand in the transportation sector. While both approaches are important, their implementation should vary by context. For example, energy efficiency improvements might be prioritized in sectors like construction and manufacturing, where technological upgrades yield immediate benefits. Reducing energy demand, however, might be more impactful in the transportation and residential sectors, where lifestyle changes can directly influence energy consumption patterns.

Hungary has introduced several policy instruments and financial mechanisms to enhance energy efficiency and support the transition toward low-carbon economic growth across various sectors. A key component of this strategy is the promotion of renewable and waste-based electricity generation through the *Feed-in Tariff system* (known by its Hungarian acronym *KÁT*). This scheme guarantees renewable energy producers a fixed purchase price above market value, ensuring the economic viability of clean energy investments (Government of Hungary 2025).

Complementing this mechanism, the Renewable Energy Support Scheme (Hungarian acronym, *METÁR)* was established in line with European Commission guidelines (Government of Hungary 2025). This provides an operational premium — a financial supplement paid above the market reference price — to renewable electricity producers. The system also prevents producers from selling electricity at negative market prices, thereby promoting efficient and market-oriented renewable generation.

In addition to these electricity market incentives, Hungary has launched several energy renovation and home modernization programs offering both repayable and non-repayable financial support. These initiatives, with a total budget of HUF 73 billion, primarily target rural and multi-child households, aiming to reduce energy consumption in the residential sector and lower emissions through improved building efficiency (Government of Hungary 2025; Hungarian National Bank 2025).

Together, these measures help achieve the sectoral decoupling of economic output from CO_2 emissions by supporting the growth of renewable energy, improving energy efficiency, and encouraging sustainable development across households and industries alike.

Hungary’s Energy Efficiency Obligation Scheme (Hungarian acronym, EKR), introduced in 2021, represents an important step toward more sustainable and efficient domestic energy use. While it may lead to higher energy prices, the scheme creates significant opportunities for end-users and businesses that invest in modernization and energy-saving projects. Its implementation responds to longstanding challenges. According to a 2020 EU-funded survey, Hungary ranked last among the EU Member States in energy efficiency performance (ONA 2021b). Despite this, the country’s Recovery and Resilience Plan, within the framework of Next Generation EU, ranks third in the EU for its contribution to climate action. However, reports by the Wuppertal Institute and E3G highlight the fact that Hungary still lacks sufficient measures to improve energy efficiency, which is an essential factor for achieving long-term sustainability and economic decoupling from carbon emissions (ONA 2021b).

The limitation of this study is that the Mann-Kendall trend test applied can identify significant monotonic trends in time series, but it cannot account for structural breakpoints. A deeper analysis would highlight the potential breakpoint in the economic time series linked to structural changes or economic crises. The authors plan a deeper dive into the effects of structural changes, such as Hungary's EU accession in 2004 and the world economic crisis in 2008, on decoupling. While this research provides an overview of the state of decoupling in Hungary over a considerable time span, due to the limitations of the method employed here, breakpoint analysis and segmented trend analysis will certainly need to be the focus of future studies.

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Appendix

Appendix 1. National economy sectors in Hungary

National economy sector by letter	National economy sector by name
A	Agriculture, forestry and fishing
B	Mining and quarrying
C	Manufacturing
D	Electricity, gas, steam and air conditioning supply
E	Water supply, sewerage, waste management and remediation activities
F	Construction

National economy sector by letter	National economy sector by name
G	Wholesale and retail trade, repair of motor vehicles and motorcycles
H	Transportation and storage
I	Accommodation and food service activities
J	Information and communication
K	Financial and insurance activities
L	Real estate activities
M	Professional, scientific and technical activities
N	Administrative and support service activities
O	Public administration and defense, compulsory social security
P	Education
Q	Human health and social work activities
R	Arts, entertainment and recreation
S	Other service activities
T	Activities of households