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Sectoral Shift-Share Analysis of Fossil Energy Consumption and Economic Growth in Croatia

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Abstract: *In the context of European climate policy and sustainable development goals, the question of the relationship between economic growth and consumption of non-renewable energy sources becomes crucial for understanding the dynamics of the transition towards a carbon-neutral economy. Croatia, as a member of the European Union, faces the challenge of balancing economic growth and decarbonization as fossil fuels still represent the main source of energy in most sectors. Although the existing literature is rich in analyses at the European Union level, there is relatively little research that examines sectoral patterns of fossil energy consumption and their relationship with economic growth in Croatia. The purpose of this paper is to analyse the relationship between fossil fuel consumption and economic growth in Croatia and to assess the extent to which decoupling of economic activity from non-renewable energy consumption has been achieved. The paper contributes to the literature by using a shift-share analysis to investigate energy changes at the sectoral level. The analysis is based on data for the period 1995-2023 and focuses on Croatia while EU-27 data are used as a benchmark. The shift-share method was applied which decomposes the total change in fossil energy consumption into three basic components: European, structural and competitive. Additionally, diagnostic indicators of energy intensity (EI) and fuel mix (FM) are included to better assess how sectoral trends contribute to fossil fuel dependency. The results indicate a relative decoupling of economic growth and fossil fuel consumption. Most sectors in Croatia show a decrease in energy intensity and the share of fossil fuels, indicating progress in the transition towards a more sustainable energy system. However, the transport sector remains the main source of growth in emissions-intensive activities thus neutralizing the positive effects of decarbonization in industry households and services. The findings suggest that further reduction of dependence on*

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fossil fuels will require deeper structural reforms, especially in transport, as well as an accelerated diversification of the energy mix in line with European climate goals.

Keywords: fossil fuel consumption; shift-share analysis; decoupling; EU-accession

JEL Classification: O43, N7

Introduction

The European Union has set the goal of becoming climate neutral by 2050, making Europe the first such continent. According to a report by the European Commission (2024), this implies a reduction in greenhouse gas (GHG) emissions by 55% by 2030 and 90% reduction proposed for 2040 compared to 1990 levels. Energy production and consumption generate over 75% of the EU's greenhouse gas emissions, making the decarbonisation of the energy system essential for meeting the EU's 2030 climate targets and its long-term goal of carbon neutrality by 2050, (European Commission, 2026). In 2020, fossil fuels were taking around 80% of primary energy consumption (Dale, 2021). Achieving this target requires a transformation of the energy system towards cleaner, more efficient solutions and a reduced dependence on fossil fuels. Defossilization and electrification are of paramount importance for the entire energy system, which are scenarios that are compatible with the Paris Agreement (Bogdanov, 2021). Renewable energy will play an important role in reaching this higher ambition, including the generation of more energy at sea and from the sea (European Commission, 2020). Many EU member states still rely heavily on fossil fuels, and Croatia is no exception. In fact, Croatia's energy profile exhibits structural characteristics that make decarbonization particularly challenging. Croatia has a strong service sector largely driven by tourism. That indirectly stimulates the transport sector where fossil-fuel-based vehicles remain dominant.

Understanding the driving factors behind fossil energy consumption changes may shed light on consumption patterns and provide a basis for assessing their developments within the context of the stated energy targets and eventually better policy design. In this context, this paper analyses trends in fossil fuel consumption not only at the aggregate national level but also across individual economic sectors. This approach allows for a more detailed understanding of how different parts of the economy contribute to the transition towards energy sustainability. However, beyond a certain income threshold, the Environmental Kuznets Curve (EKC) hypothesis suggests that technological progress and structural shifts from industry toward services contribute to improved environmental quality and declining emission levels.

Accordingly, the analysis covers four sectors (industry, transport, households, and services) which together account for approximately 95% of total final energy

consumption in Croatia. In addition to the sectoral perspective, the paper examines changes in fossil fuel consumption before and after Croatia's accession to the European Union in order to assess whether EU membership has affected fossil fuel consumption patterns. The research examines the resource decoupling process in Croatia, which explains the reduction of resource consumption per unit of economic output and the reduction of environmental impacts of the resources used. In line with the above discussion, the research concentrates on three core research questions:

RQ1: To what extent has economic growth in Croatia been decoupled from fossil fuel consumption over the period 1995-2023?

RQ2: How do different economic sectors contribute to changes in fossil fuel consumption in Croatia, and which components, European, structural, or national, dominate these changes?

RQ3: Has Croatia's accession to the European Union altered sectoral fossil fuel consumption patterns and the relationship between economic growth and fossil fuel use?

In order to answer these research questions, the observed period is divided into two sub-periods: the pre-accession period (1995-2013) and the post-accession period (2014-2023).

This paper combines three complementary approaches to better understand the relationship between economic growth and fossil fuel consumption:

1. Shift-share analysis is applied to quantify the contribution of individual sectors to changes in fossil fuel consumption and to distinguish between broader EU influences, structural effects, and country-specific factors. In other words, shift-share analysis helps identify where changes are taking place (industry, transport, households and services) and which component dominates (EU trends, structural effects or national factors).
2. Energy intensity (EI) and fuel mix (FM) indicators are used to explain differences across sectors in the efficiency of fossil fuel use and the extent to which individual sectors rely on fossil fuels relative to cleaner energy alternatives.
3. The decoupling index (DI) is calculated as a macroeconomic indicator capturing the relationship between economic activity and fossil fuel consumption. This provides a broader perspective on the extent to which economic growth in Croatia has been decoupled from fossil fuel use and offers additional insight into the transition towards a more sustainable energy system.

Although the relationship between energy consumption and economic growth has been extensively examined in the empirical literature, most studies focus on aggregate energy measures and country-level analyses (Ozturk, 2010; Kalimeris et al., 2014; Dan Armeanu et al., 2017). There has been far less exploration of the sectoral aspect of fossil energy consumption, especially regarding structural changes in the economy. Additionally, existing research seldom uses shift-share decomposition methods

to separate energy consumption changes caused by within-sector intensity effects from those resulting from shifts in the economic structure across sectors (Borozan, 2018; Fernández González et al., 2014). This gap is particularly noticeable in small, post-transition economies, where sectoral differences and structural dynamics could significantly influence energy-growth relationships. This study addresses that gap by offering a sectoral shift-share analysis of fossil energy consumption and its link to economic growth in Croatia. The result of this paper contributes to the field threefold. First, it evaluates the size of each effect over the study period. Second, it identifies the patterns of sectoral specialization in fossil fuel consumption in Croatia and then assesses their stability over the period 1995–2023. Third it examines the fossil fuel decoupling process. The findings of this study add to the literature linking the EKC to resource decoupling, demonstrating how economic development can lead to a reduction in fossil fuel consumption intensity and associated environmental impacts. The results of this paper contribute to the literature in three main ways. First, it quantifies the relative size of the European, structural (industry-mix), and national (competitive) effects driving changes in fossil fuel consumption in Croatia over the study period. Second, it identifies patterns of sectoral specialization in fossil fuel consumption across industry, transport, households, and services, and assesses their stability over time. Third, it evaluates the extent of fossil fuel decoupling from economic growth using complementary indicators of energy intensity, fuel mix, and the decoupling index.

This paper is structured as follows. The introduction is followed by a literature review that presents the most relevant studies linking fossil fuel consumption and economic development as well as studies that apply the shift-share technique to the analysis of energy consumption. The third section explains the data and methodology. The data are obtained from Eurostat and refer to fossil fuel consumption (total and by sector), gross value added by sector and Croatia's GDP. The methodological framework includes shift-share analysis, complemented by the calculation of energy intensity (EI), the fuel mix (FM) indicators and the decoupling index (DI). The results are presented in the fourth section, followed by a discussion in the fifth section, while the sixth section concludes the paper.

Literature review

Fossil fuel consumption and economic development

The idea of decoupling environmental pressure from economic growth has been formally introduced in policy-oriented literature, particularly by the OECD (2002). Decoupling occurs when economic growth is accompanied by a slower increase, or even a reduction, in environmental pressure, weakening the connection between

economic activity and environmental degradation. The OECD identifies two types of decoupling: relative decoupling, where environmental pressures grow but at a slower pace than the economy, and absolute decoupling, where environmental pressures decline even as the economy continues to grow. The OECD also stresses that decoupling is influenced by factors like changes in energy intensity, fuel mix, technological progress, and the economic structure, rather than income growth alone. This view underscores the importance of disaggregated and sector-level analyses to reveal how economic growth interacts with fossil energy use, as aggregate indicators can obscure diverse sectoral patterns and adjustment processes.

Recent EU studies (Kalimeris, et al., 2014, Armeanu, et al., 2017) identify a positive and statistically significant link between energy consumption and economic growth, although evidence on causality remains mixed. These differences largely reflect variations in sample composition, econometric methods, time periods, energy types, model specifications, and country-specific characteristics such as energy structures, sectoral composition, and policy frameworks (Ozturk, 2010).

Jiang et al. (2019) have examined the role of sector-level energy consumption on carbon emissions of several fossil fuels and have found that energy-intensive sectors and large investments in infrastructure accelerate industrialisation and urbanisation, thus increasing emissions. On the contrary, emissions from non-energy sectors start to decline in the post-industrial phase. The same results are proven in the case study presented by Csalódi, et al. (2022) in two counties, Sweden and Qatar from 1990 to 2018. Qatar has peaked at the maximum GHG value in the examined time, while Sweden could significantly decrease their GHG emission. Empirical evidence based on disaggregated data indicates that improvements in energy efficiency, reflected in declining energy intensity, represent a key mechanism behind reductions in energy consumption, even during periods of sustained economic growth (Lin et al., 2019).

Building on the decoupling framework, empirical evidence for the European Union suggests that weakening the link between economic growth and environmental pressure relies primarily on changes in energy intensity and structural adjustments, rather than income growth alone. Using EU data, Sekur, Rogić Dumančić and Mustač (2020) show that decoupling outcomes are closely associated with improvements in energy efficiency and shifts in the composition of economic activity, highlighting the importance of disaggregated approaches when analyzing energy–growth relationships. These findings reinforce the view that sector-level analyses are essential for understanding how changes in fossil energy consumption emerge.

The link between economic growth and environmental degradation has been widely discussed in the literature, particularly through the Environmental Kuznets Curve (EKC) framework. However, Stern (2004) offers a critical reassessment, arguing that the commonly assumed inverted U-shaped relationship between income and environmental pressure is neither theoretically sound nor consistently supported across countries and pollutants. Instead, Stern (2004) suggests that environmental

changes often attributed to income growth are better explained by shifts in energy use patterns, such as fossil energy consumption, energy intensity, technological progress, and sectoral composition. Moreover, using highly aggregated indicators can obscure the sectoral dynamics driving changes in environmental pressure. This critique highlights the need for analytical methods that can separate within-sector changes in energy intensity from structural shifts across sectors to better understand the interplay between economic growth and fossil energy use.

This body of literature suggests that aggregate analyses of the energy–growth relationship can overlook important sectoral mechanisms, emphasizing the need for approaches that explicitly consider differences in energy intensity, fuel structure, and sectoral composition.

Shift-share framework

The original purpose of shift-share analysis was to emphasize, especially, the part of regional growth or decline in an industry which is region-specific. It was originally developed as a regional growth forecasting tool to assess whether deviations from national average growth indicate a region's equally stronger performance across industries (Esteban, 2000). The regional shift component measures the region's relative performance in a specific industry. A positive shift indicates a comparative locational advantage, and a negative shift the opposite (Stevens, Moore, 1980).

Probably the most important issue raised in the literature concerns the relationship between the industrial mix (IM) and regional shift (RS) components (Stevens, Moore, 1980, p. 430). Stilwell (1969) explains that regional growth may stem from both industrial mix and industrial shift effects. In most regions, growth is mostly driven by a favourable industrial mix, where employment is concentrated in nationally fast-growing industries. Generally, the regional shift (RS) component is smaller than the industrial mix (IM) component for a given industry and is almost always smaller than the combined IM and national share (NS) effects. Using a limited sample of seven regions of Maryland for the 1960-1970 period, Berzeg (1978) shows that industrial mix components are statistically significant and that regional shifts are not random. These findings indicate that shift-share analysis provides a valid framework for explaining the forces underlying regional industrial growth.

Concerns regarding structural change and related issues raised by various authors create questions about the correct interpretation of the various shift-share components. The regional shift (RS) component can give the wrong signal to the analyst unless it is used carefully. However, shift-share analysis remains highly valuable for offering rapid, inexpensive, and useful indications of past regional performance and to identify problems which may deserve the attention of public policy-makers or may require further study (Stevens, Moore, 1980). Over the past two decades, it has also

been applied to decompose key variables, primarily employment and value added, at the cross-country level, including analyses at the EU level (Esteben, 2000; Batóg et al., 2007). Subsequently, energy has also emerged as a key variable in cross-country analyses (Fernández González, et al., 2014).

Using a refined Laspeyres model to determine the influence of several factors (output, energy intensity, structure, fuel mix and utility mix), Diakopulaki and Mandraka (2007) concluded that most EU countries have made a considerable but not always sufficient effort to decouple emissions from industrial growth. Applying shift-share analysis, Gilli et al. (2013) assessed the environmental performance of five EU countries (Germany, Italy, France, the Netherlands, and Sweden) relative to the EU-27 average over the 2006–2008 period. Their results indicate that, with some exceptions, the selected countries generally outperform the EU-27 average. Fernández González et al. (2014) used the logarithmic mean Divisia index method (LMDI) to examine changes in aggregate energy consumption in the EU-27 from 2001 to 2008. Their findings suggest that these changes were driven not only by economic growth in Europe but also by shifts in countries' production structures. The LMDI decomposition of GHG and AG emissions[1] for EU countries for the period 2008-2016 by Lodi and Bertarelli (2024) showed that the overall level of emissions in the EU countries stays constant, but heterogeneous effects are recorded.

The analysis of regional electricity consumption changes by Grossi and Mussini (2018) at the NUTS3 level in Italy over the period 2000-2013 was carried out by introducing a spatial shiftshare decomposition measuring the neighbourhood effect on regional energy efficiency change. The findings show that a shift toward less electricity-intensive activity sectors has occurred in almost all regions, reducing regional electricity consumption.

However, shift-share analysis does not identify the primary causes of each effect. It cannot explain why individual EU Member States experience different trends in final energy consumption compared to the EU, nor why certain energy end-use sectors grow or decline more rapidly than their EU counterparts. Moreover, the results do not explain whether reductions in sectoral energy consumption show improved energy efficiency or a contraction in economic activity (Borozan, 2018). Addressing these problems requires country-specific and sector-level analyses within each EU Member State.

Recent methodological advancements have enhanced the shift-share framework, broadening its analytical scope and interpretive value. Montanía et al. (2024) introduce a more comprehensive approach to shift-share analysis that addresses some limitations of traditional methods, particularly in capturing complex structural dynamics across regions and sectors. Their work highlights the flexibility of shift-share methods in breaking down observed changes into meaningful components, while stressing the need for careful interpretation of within-unit and structural effects. Although their framework was developed in a regional context, it underscores the use-

fulness of shift-share analysis as a robust and transparent tool for studying structural and compositional changes with disaggregated data. This perspective supports using sectoral shift-share analysis in energy consumption studies, where changes can stem from both sector-specific intensity adjustments and shifts in the economic structure.

While recent extensions enrich the methodological framework, the present study relies on the classical shift-share logic, which remains well suited for sectoral analyses with limited data requirements and a clear interpretative structure.

In response to the gaps in the literature, this study uses a sectoral shift-share framework to analyse changes in fossil energy consumption in Croatia. The approach breaks down total energy consumption changes into within-sector intensity effects and structural effects from shifts in the sectoral makeup of the economy, providing a more detailed view of sectoral dynamics compared to aggregate analyses. By applying this method to sector-level data, the study offers empirical insights into how much sectoral intensity versus structural change influences fossil energy consumption patterns and their connection to economic growth.

Methodology and data

Shift-share analysis is a statistical method originally developed within the field of regional economics. It is a simple descriptive technique used to analyse the relative growth of a region in comparison with other regions. Dunn (1960) was the first to apply shift-share analysis to estimate regional growth and to assess the importance of specific industries for regional performance with shifts typically measured using employment or gross value added. Traditional shift-share analysis consists of three components (Stimson et al., 2006):

a) National share (NS) - the portion of regional change attributed to overall national growth trends;
b) Industrial mix (IM) - the portion of regional change attributed to the industrial composition or sectoral structure of the region;
c) Regional shift (RS) - the portion of regional change attributed to the competitive advantages or disadvantages of the region relative to the rest of the country.

In other words, shift-share analysis seeks to determine which part of the growth in employment or gross value added in a region can be attributed to overall national growth, the industrial structure of the region or factors specific to that region. When applied in the context of energy consumption, this paper uses the shift-share technique to examine the extent to which individual sectors of the economy (industry, transport, households and services) contribute to fossil fuel consumption in Croatia. In addition, shift-share analysis makes it possible to quantify the extent to which changes in fossil fuel consumption in Croatia follow general EU trends, arise from the domestic economic structure or reflect national specificities.

More specifically, shift-share analysis enables the decomposition of changes in fossil fuel consumption across four economic sectors (industry, transport, households, and services) into clearly distinguishable components. Adopting terminology commonly used in regional economics, the three components of the shift-share analysis are defined as follows:

a) General "European" effect (N) - the portion of the change in fossil fuel consumption in Croatian sectors attributable to overall trends in fossil fuel consumption at the European Union level;
b) Structural (industry-mix) effect (IM) - the portion of the change in fossil fuel consumption attributable to sector-specific trends at the EU level relative to the overall change in fossil fuel consumption in the EU;
c) Competitive (national) effect (C) - the portion of the change in fossil fuel consumption attributable to national specificities, corresponding to the difference between the actual change in consumption and the combined European and structural effects.

The three-component shift-share model can therefore be expressed as follows (adapted from Stimson et al., 2006, p. 115):

$$\Delta e_i \equiv e_{i,t} - e_{i,t-1} = N_i + IM_i + C_i$$

Where:

$$N_i \equiv e_{i,t-i}\left(\frac{E_t}{E_{t-1}} - 1\right)$$

$$IM_i \equiv e_{i,t-i}\left(\frac{E_{i,t}}{E_{i,t-1}} - \frac{E_t}{E_{t-1}}\right)$$

$$C_i \equiv e_{i,t-i}\left(\frac{e_{i,t}}{e_{i,t-1}} - \frac{E_{i,t}}{E_{i,t-1}}\right)$$

Where:

e_i and E_i represent fossil fuel consumption in sector *i* in Croatia and the European Union, respectively;

e and *E* denote total fossil fuel consumption in Croatia and the European Union across all sectors;

t–1 denotes the initial year of the analysed sub-periods (1995 for the period 1995–2013 and 2014 for the period 2014–2023), while *t* denotes the final year of the respective sub-periods (2013 and 2023).

The positive value of the European effect (N) indicates that fossil fuel consumption by sector in Croatia is influenced by positive EU trends. A negative structural (industry-mix) effect (IM) indicates that the corresponding sector at the EU level is reducing fossil fuel consumption faster than the EU average, while a positive value

points to the opposite trend. Finally, a positive competitive (national) effect (C) suggests that fossil fuel consumption by sector in Croatia is growing faster than general EU and EU-sectoral trends, while negative values point to better national performance compared to the benchmarks. Shift-share analysis identifies the "sources of change" across sectors showing how much each component contributes to changes in fossil fuel consumption by sector but it does not explain why these changes occur. To address this limitation, the analysis is complemented by indicators of energy intensity (EI) and the fuel mix (share of fossil fuels) (FM) at the sectoral level. These indicators measure how much energy is consumed per unit of output and the extent to which energy consumption relies on fossil fuels. In this way, EI and FM help explain the underlying drivers of the changes identified by the shift-share analysis such as improvements in efficiency and shifts towards renewable energy sources.

Energy intensity (EI) measures the energy requirements of an economy and is commonly used as an indicator of energy efficiency. It is defined as the amount of energy consumed per unit of GDP (Eurostat, 2025). The formula can be written as follows:

$$EI_{i,t} \equiv \frac{e_{i,t}}{y_{i,t}}$$

$$EI_{i,t-1} \equiv \frac{e_{i,t-1}}{y_{i,t-1}}$$

Where:

$e_{i,t-1}$ and $e_{i,t}$ denote fossil fuel consumption in sector i in the initial and final year of each analysed sub-period, respectively (1995 and 2013 for the period 1995–2013, and 2014 and 2023 for the period 2014–2023);

$y_{i,t-1}$ and $y_{i,t}$ denote gross value added in sector i in the initial and final year of each analysed sub-period, respectively (1995 and 2013 for the period 1995–2013, and 2014 and 2023 for the period 2014–2023).

The relative (percentage) change in energy intensity (EI) is given by:

$$\%\Delta EI_i \equiv \frac{EI_{i,t} - EI_{i,t-1}}{EI_{i,t-1}}$$

The fuel mix (FM) is an indicator that measures the share of fossil fuel consumption in total energy consumption in Croatia. A decrease in the FM indicator implies a higher degree of diversification towards renewable energy sources. The relative (percentage) change in the FM indicator is given by:

$$\%\Delta FM_i \equiv \frac{FM_{i,t} - FM_{i,t-1}}{FM_{i,t-1}}$$

Where:

$FM_{i,t-1}$ and $FM_{i,t}$ denote the shares of fossil fuels in total energy consumption in sector i in the initial and final year of each analysed sub-period, respectively (1995 and 2013 for the period 1995–2013, and 2014 and 2023 for the period 2014–2023).

Finally, the decoupling index (DI) provides a macro-level perspective on the relationship between economic growth and fossil fuel consumption. The OECD (2002, p. 4) defines decoupling as "the disconnection between environmental pressures and economic growth". In the field of climate change, decoupling refers to the breakage of links between carbon emissions and economic output (Jiang, et al., 2019 according to UNEP, 2011). Decoupling occurs when the growth rate of an environmental pressure is less than that of its economic driving force (e.g. GDP) over a given period. It takes place when there is technological progress, i.e., the use of renewable energy (Lodi, Bertarelli, 2024). Decoupling can be either absolute or relative. Absolute decoupling occurs when the environmentally relevant variable is stable or declines while the economic driving force continues to grow, whereas relative decoupling occurs when the environmentally relevant variable increases but at a slower rate than the economic variable.

Decoupling is measured using a decoupling indicator that relates changes in environmental pressure to changes in economic activity. In this paper, the decoupling index is calculated using fossil fuel consumption as the environmental pressure variable in the numerator, while the economic variable (GDP) is in the denominator. Following OECD (2002), the decoupling index (DI) is defined as:

$$DI \equiv \frac{\%\Delta E}{\%\Delta Y}$$

$$\%\Delta E = \frac{E_t - E_{t-1}}{E_{t-1}}$$

$$\%\Delta Y = \frac{Y_t - Y_{t-1}}{Y_{t-1}}$$

Where:

E denotes the environmental variable, where E_{t-1} and E_t represent total fossil fuel consumption in Croatia in the initial and final year of the analysed period, i.e. 1995 and 2023, respectively;

Y denotes the economic variable, where Y_{t-1} and Y_t represent Croatia's total GDP in the same initial and final year, i.e. 1995 and 2023, respectively.

Unlike EI and FM, which are analysed for two sub-periods, the decoupling index is calculated for the entire period (1995–2023) in order to capture long-term macroeconomic trends. The interpretation of the decoupling index (DI) is as follows:

DI < 0 - absolute decoupling (fossil fuel consumption decreases while GDP increases);

0 < DI < 1 - relative decoupling (fossil fuel consumption increases but at a slower rate than GDP);

DI = 1 - no decoupling;
DI > 1 -negative decoupling (fossil fuel consumption increases faster than GDP).

The analysis covers the period from 1995 to 2023 which provides a sufficiently long-time frame to examine the effects of Croatia's EU membership on fossil fuel consumption and the associated indicators. The empirical analysis is based on sectoral data for Croatia and corresponding aggregate data for the European Union (EU-27), which are used as a benchmark in the shift-share decomposition. All data are obtained from Eurostat and a detailed description of the variables is provided in Table 1.

Table 1: Variables used in the analysis and their description

Variable	Notation	Description	Used in	Unit	Source
Fossil fuel consumption	E_i	Fossil fuel consumption in sector *i* in Croatia; includes solid fossil fuels, natural gas and oil and petroleum products (excluding biofuels)	Shift-share analysis, Energy intensity (EI) and Decoupling index (DI)	Thousand tonnes of oil equivalent (ktoe)	Eurostat, Simplified energy balances (nrg_bal_s)
Gross value added (GVA)	Y_i	Gross value added of the industry, transport and services sectors in Croatia	Energy intensity (EI)	Million EUR (2015=100)	Eurostat, Gross value added by industry (nama_10_a64)
Household final consumption expenditure	Y_i	Household final consumption expenditure by purpose (COICOP), used as a proxy for economic output of households	Energy intensity (EI)	Million EUR (2015=100)	Eurostat, Household final consumption expenditure (nama_10_co3_p3)
Gross domestic product (GDP)	Y_i	Total GDP of Croatia	Decoupling index (DI)	Million EUR (2015=100)	Eurostat, *GDP and main components* (nama_10_gdp)

Based on the previously described methodological framework and data, the next section presents the empirical results of the analysis in three parts. First, a shift-share analysis is applied to identify the main drivers of changes in fossil fuel consumption across Croatian sectors. Second, trends in energy intensity (EI) and the share of fossil fuels (FM) in total energy consumption are examined at the sectoral level. Finally, the decoupling index (DI) is analysed to assess the extent to which economic growth in Croatia has been decoupled from total fossil fuel consumption.

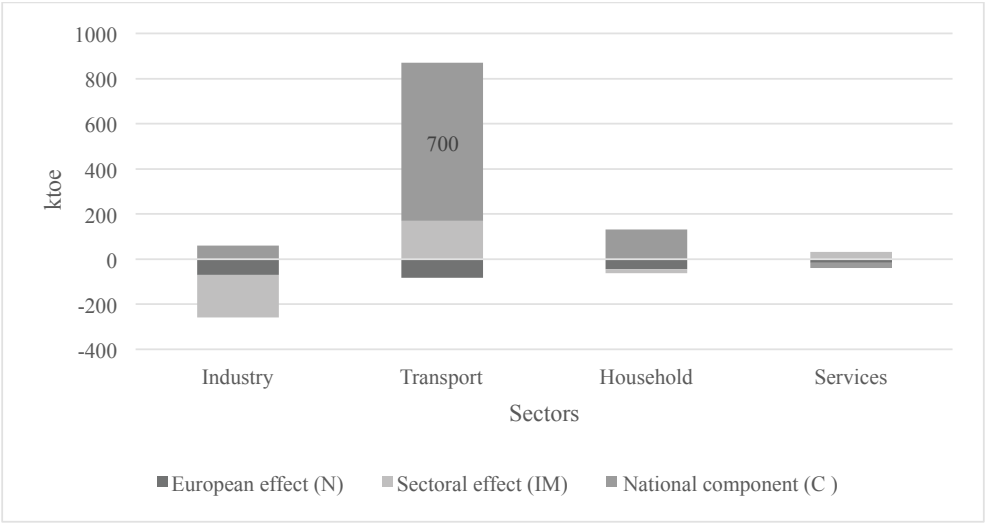
Results

Graphs 1 and 2 present the shift-share decomposition of changes in fossil fuel consumption in Croatia for two distinct periods: before accession to the European Union

(1995-2013) and after accession to the EU (2014-2023). The purpose of this comparison is to assess whether fossil fuel consumption patterns changed following Croatia's accession to the EU with particular emphasis on sectoral differences. The results indicate that the overall structure of the decomposition has not changed substantially and has remained relatively stable across both periods.

In the pre-accession period (1995-2013), changes in fossil fuel consumption are largely driven by the national component (C) (Graph 1). This effect is especially pronounced in the transport sector where the national component clearly dominates in explaining the strong growth in fossil fuel consumption, accounting for approximately 700 ktoe of the total increase. In shift–share terms, this implies that the expansion of fossil fuel use in transport was primarily driven by country-specific factors rather than by general European trends or sectoral dynamics at the EU level. During this period, the European effect (N) plays a relatively modest role, while the structural effect (IM) predominantly contributes to a reduction in consumption, particularly in industry. The decline in fossil fuel consumption in the industrial sector prior to 2013 can be linked to restructuring processes and deindustrialisation in Croatia (see Penava, 2014). The decrease was also recorded between 2008 and 2010 in research by Lodi and Bertarelli (2024) and likely linked to the economic crisis of 2008, which led to a decline in the real GVA for EU countries.

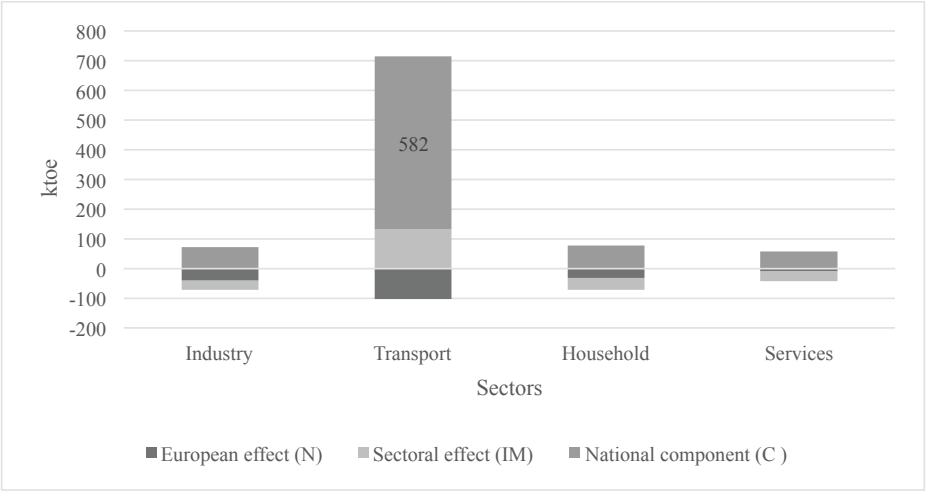
Graph 1: Shift-share decomposition of fossil fuel consumption (ktoe), 1995-2013



Source: Authors' own calculations based on data from Eurostat (n.d.-a)

In the period following Croatia's accession to the EU (2014–2023), the European effect (N) was expected to strengthen as a result of alignment with EU climate objectives and regulatory frameworks (Graph 2). However, the results do not confirm this expectation. The European effect (N) remains weak and is even negative in some sectors suggesting that EU-level developments have not exerted a decisive influence on fossil fuel consumption patterns in Croatia. As in the pre-accession period, the national component (C) continues to dominate, particularly in the transport sector which remains the primary driver of growth in fossil fuel consumption.

Graph 2: Shift-share decomposition of fossil fuel consumption (ktoe), 2014-2023



Source: Authors' own calculations based on data from Eurostat (n.d.-a)

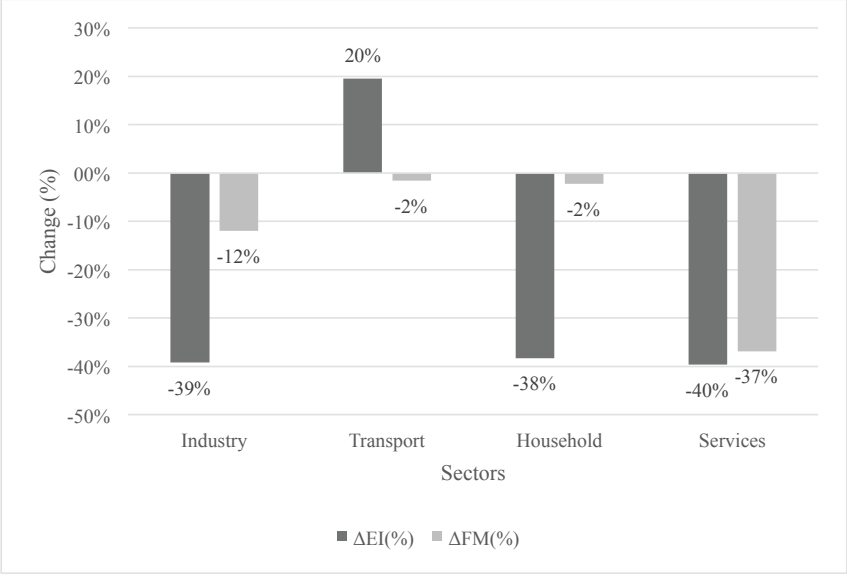
A comparison of the two periods shows that the basic structure of the decomposition did not change significantly after Croatia's accession to the EU. In both periods, transport stands out as the sector with the most pronounced positive national effect (C) suggesting that domestic factors, such as the growth of road traffic[2], tourism-related demand, and the limited penetration of alternative fuels, continue to outweigh European decarbonisation incentives. In contrast, industry and households exhibit more moderate changes, with the structural effect (IM) primarily acting in the direction of reducing fossil fuel consumption. The results of the shift-share analysis therefore indicate that Croatia's EU membership alone was not sufficient to significantly alter the structure of fossil fuel consumption. The research by Borozan (2018) shows that European effect turned out to be the dominant effect in the second (2008-2010) and third (2011-2015) sub-period, particularly in large states and states very dependent on Russian gas supplies. The dominance of the national component (C), particularly in the transport sector, highlights the importance of domestic policies in

reducing fossil fuel use while the European framework appears to function more as a contextual influence than as the main driver of change.

The shift-share analysis is complemented by indicators of energy intensity (EI) and the fuel mix, i.e. the share of fossil fuels in total energy consumption (FM). Graphs 3 and 4 illustrate changes in these indicators by sector for the periods 1995-2013 and 2014-2023. Graph 3 shows that most sectors experienced a decline in energy intensity indicating improved efficiency in fossil fuel use. A similar decline in EI is observed in industry, households and services where economic growth was accompanied by slower growth or even a reduction in fossil fuel consumption. Those results are similar as Borozans' (2018) which showed that sectoral effect had a negative value in most of the EU states specializing in activities consuming less energy, such as states with developed tourism and smaller states, or in post-transition EU states that consume less per capita energy than the "older" EU states in general.

The main exception is the transport sector where energy intensity increased, implying that fossil fuel consumption grew faster than sectoral GVA. Specifically, during this period, transport GVA increased by approximately 45%, while fossil fuel consumption rose by as much as 73%, leading to a deterioration in energy efficiency. Regarding the share of fossil fuels (FM), a decline is observed in most sectors, particularly in services and industry, indicating gradual diversification of the energy mix. In contrast, the share of fossil fuels in transport remained largely unchanged, further confirming the sector's strong dependence on fossil fuel sources.

Graph 3: Change of energy intensity (EI) and fuel mix (FM) indicators, 1995-2013

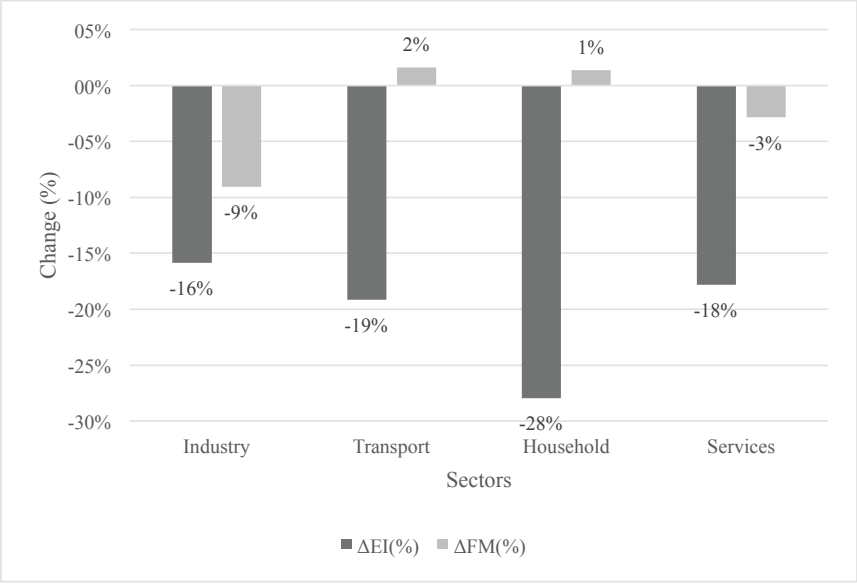


Source: Authors' own calculations based on data from Eurostat (n.d.-a, n.d.-b n.d.-c)

In the period following Croatia's accession to the European Union (2014-2023), all sectors recorded a further decline in energy intensity (EI) (Graph 4). The transport sector is particularly noteworthy as it also experienced a decrease in EI during this period, in contrast to the earlier period. This development is explained by the fact that transport GVA increased by approximately 65%, while fossil fuel consumption rose at a much slower rate, by around 33%. This indicates an improvement in energy efficiency in the transport sector. In the remaining sectors (industry, households and services), the downward trend in energy intensity continued, albeit at a more moderate pace. This suggests that the most substantial improvements in energy efficiency were achieved in the earlier period, while the later period was characterised by more gradual gains.

With respect to the share of fossil fuels (FM), changes after 2014 are relatively limited. In most sectors, FM either slightly declined or stagnated, whereas in transport the share of fossil fuels remains very high with only marginal improvements. This finding indicates that, despite progress in energy efficiency, the structure of the energy mix continues to represent a key challenge for economic policymakers, particularly in the transport sector.

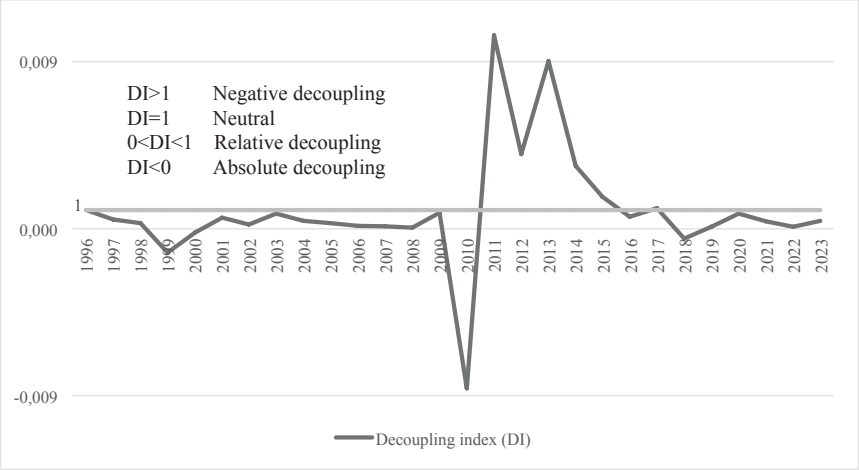
Graph 4: Change of energy intensity (EI) and fuel mix (FM) indicators, 2014-2023



Source: Authors' own calculations based on data from Eurostat (n.d.-a, n.d.-b n.d.-c)

The decoupling index (DI) compares changes in GDP with changes in fossil fuel consumption. An index value below zero indicates absolute decoupling, while a value between zero and one signals relative decoupling. Graph 5 illustrates the evolution of the DI in Croatia over the period 1995-2023, revealing distinct phases in the relationship between economic activity and fossil fuel consumption. For most of the period prior to the global financial crisis, DI values were close to or slightly below 1, indicating weak relative decoupling, that is, a largely parallel movement of GDP and fossil fuel consumption. The period of the global financial crisis and its immediate aftermath was characterised by unstable and extreme DI values. As a result, the evolution of the DI cannot be interpreted linearly over the entire period, since the crisis years were marked by pronounced disruptions in both economic activity and fuel consumption. The year 2010 is particularly notable, as GDP stagnated (with growth of only 0.3%) while fossil fuel consumption declined by approximately 2.3%. This combination led to a strongly negative DI value (-8.6), which reflects an arithmetic effect caused by a very small denominator rather than evidence of strong or persistent absolute decoupling. A similar interpretation applies to the period 2011-2013, during which very high positive DI values were recorded. In these years, GDP either declined slightly or stagnated, while fossil fuel consumption decreased much more rapidly resulting in exaggerated index values. These outcomes indicate that during the crisis and post-crisis period, the DI should not be interpreted as a reliable indicator of long-term decoupling between economic growth and fossil fuel consumption, but rather as a reflection of short-term macroeconomic disturbances. After 2014, with the gradual recovery of the economy, DI values become more stable and mostly remain below 1. This pattern indicates relative decoupling; whereby economic growth is no longer accompanied by a proportional increase in fossil fuel consumption. However, the absence of persistently negative DI values suggests that absolute decoupling has not been systematically achieved. Although fossil fuel intensity has declined, these efficiency gains have been largely offset by the continued growth of energy-intensive activities, particularly transport. This is consistent with the shift-share results, which show a strong positive national component in the transport sector (around +700 ktoe) (see graph 1), indicating that growth in transport activity continues to drive overall fossil fuel consumption despite efficiency improvements.

Graph 5: Movement of the decoupling index (DI), 1995-2023



Source: Authors' own calculations based on data from Eurostat (n.d.-a, n.d.-d)

Discussion

The results of the empirical analysis indicate several consistent patterns in fossil fuel consumption trends in Croatia over the period 1995-2023. The combined use of shift-share decomposition, the indicators of energy intensity (EI) and the fuel mix (FM), as well as the decoupling index (DI) allows for a more detailed understanding of fossil fuel consumption dynamics, both at the sectoral level and over time.

The shift-share analysis shows that changes in fossil fuel consumption in Croatia in both observed periods (1995-2013 and 2014-2023) are largely driven by the national component (C), while the European (N) and structural (IM) effects remain relatively weak. This finding suggests that trends in Croatia cannot be primarily explained by general EU-wide trends in fossil fuel consumption or by differences in sectoral growth rates at the EU level but are instead mainly shaped by domestic factors. The transport sector stands out in particular, as it makes a strongly positive contribution to the national component (C) in both periods and largely offsets reductions in fossil fuel consumption observed in industry and households. Although Croatia's accession to the European Union could have been expected to strengthen the European effect (N) through alignment with common energy and climate policies, the results do not indicate a significant change in the structure of the decomposition after 2013. The European effect (N) remains weak in the post-accession period, suggesting that EU membership alone was insufficient to substantially alter domestic fossil fuel consumption patterns.

Fuel mix indicator (FM) further confirms that the process of decarbonisation has been uneven across sectors. Industry and households record a more pronounced decline in the share of fossil fuels, while changes in the transport sector remain modest, particularly after 2014. This pattern helps explain the strong national component (C) observed in the shift-share analysis for transport, as growth in this sector continues to rely heavily on fossil fuels.

Finally, the decoupling index (DI) indicates that relative decoupling between economic growth and fossil fuel consumption has been achieved for most of the period under analysis. However, the pronounced oscillations in DI during and immediately after the global financial crisis highlight the limitations of this indicator in years of stagnation or very weak GDP growth. The extreme DI values observed during this period reflect the arithmetic sensitivity of the index rather than a structural decoupling of economic growth from fossil fuel consumption. In the post-crisis period, the DI stabilises, but the results point to relative rather than absolute decoupling.

Conclusion

The aim of this paper was to analyse the relationship between economic growth and fossil fuel consumption in Croatia and to identify the sources of changes in energy consumption at the sectoral level by applying shift-share analysis, energy intensity indicators, fossil fuel shares and the decoupling index. The results show that reductions in fossil fuel consumption in Croatia have occurred primarily in industry and households, while the transport sector remains a key obstacle to lowering overall fossil fuel use. Despite some improvement in energy efficiency in transport after 2014, the growth of activity in this sector continues to generate increased fossil fuel consumption, which is clearly reflected in the strong national component of the shift-share decomposition. Croatia's accession to the European Union has not resulted in a visible strengthening of the European effect in reducing fossil fuel consumption, highlighting the limitations of common policies in the absence of stronger national involvement. At the same time, the EI and FM indicators confirm the presence of relative decoupling, but not a structural reduction in dependence on fossil fuels across all sectors. Further reductions in fossil fuel dependence would therefore require stronger interventions in sectors with a pronounced national component, particularly transport, in order to transform relative decoupling into absolute decoupling in the long run.

This research has several limitations that should be considered when interpreting the results. First, shift-share analysis does not allow for the identification of causal relationships between economic activity and fossil fuel consumption. The estimated effects therefore reflect the relative contributions of different components rather than their underlying causes. Second, the analysis relies on aggregated sectoral data which limits insight into intra-sectoral changes, such as technological developments. This

limitation is especially relevant for the transport sector which has various forms of transport with very different energy characteristics. Third, the decoupling index is highly sensitive in periods of weak GDP growth or economic stagnation which can result in extreme values that do not reflect genuine structural changes in the energy system. Consequently, DI results should be interpreted alongside information on GDP dynamics and absolute levels and trends in fossil fuel consumption.

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Conflicts of interest/Competing interests

There is no conflict of interest/Competing interests.

Availability of data and material

The data that support the findings of this study are openly available in the website of Eurostat (https://ec.europa.eu/eurostat).

Code Availability

No custom computer code was used in this study. All results are reported in the tables and figures presented in the manuscript.

Authors' Contributions

Tomislav Sekur conceived the research idea, designed the methodology, conducted the empirical analysis, and served as the corresponding author.

Alka Obadić contributed to the conceptual framework of the study, participated in the partial preparation of the literature review, and critically evaluated the structure of the conclusion and discussion.

Lucija Rogić contributed to data collection and preparation, participated in the literature review, assisted in the interpretation of results, and supported the writing and editing of the manuscript.

All authors reviewed and approved the final version of the paper.

NOTES

[1] GHG denotes carbon dioxide (CO_2), methane and nitrous oxide and AG denotes sulphur dioxide (SO_2), nitrous oxide and ammonia in thousand tonnes.

[2] Between 2001 and 2015, more than 633 km of full-profile motorways were constructed under the jurisdiction of Hrvatske autoceste d.d. (Ministry of the Sea, Transport and Infrastructure, n.d.).

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