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Sectoral Impacts on Energy Intensity: Developed V/s Developing Nations

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The proportion of energy consumed by agriculture, industry, services, and transportation sectors exert varying effects on the overall energy intensity of economies. This analysis examines the sectoral contributions to energy intensity in both developed and developing countries. In developed nations, increased agricultural energy consumption has contributed to reductions in energy intensity. Conversely, heightened industrial energy use in developing countries tend to elevate their energy intensity, whereas the adoption of renewable energy sources support energy intensity reduction within these economies.

I. Introduction

Energy demand is rising across nearly all sectors of the economy due to factors such as population growth, increasing consumer needs, energy-intensive industries, transportation expansion, and globalization. In this paper, we explore whether the growth in energy consumption among different sectors—agriculture, industry, services, and transportation—affects the overall energy intensity of developed and developing economies in varied ways. The effectiveness of energy conservation is often measured using both energy consumption and energy intensity as dual indicators (Yan et al., 2022). Rising energy consumption in different sectors can negatively affect an economy if sustainable practices are not adopted to improve energy intensity. For example, excessive energy use in agriculture can cause environmental harm, including increased greenhouse gas emissions and water degradation (Wu & Ding, 2021). Sectoral energy consumption insights may differ from those based on national-level data (Smyth & Narayan, 2015). The industrial sector is typically highly energy-intensive, while the transportation sector's intensity varies depending on transport modes and fuel types; agriculture generally falls somewhere in the middle. If a certain energy intensity threshold is surpassed, increased energy consumption can hinder economic growth (Aydin & Esen, 2018). Therefore, new energy policies should carefully consider energy intensity.

When designing sector-specific energy policies, it is crucial to understand how increased energy consumption in a particular sector might either hinder or promote overall economic energy efficiency. Higher energy use does not always translate to greater energy intensity or lower ef-

iciency. Recognizing this distinction is vital to balancing growing energy demands with efforts to maintain lower energy intensities. For a more sustainable and efficient energy landscape, analyzing and addressing the consumption patterns in each sector are essential. This approach enables the implementation of technologies, policies, and practices that can optimize energy use across sectors, which is the main motivation of our study.

Convergence in sectoral energy consumption is unlikely, as policies such as subsidies, savings targets, and renewable energy requirements differ across sectors and can have varied impacts on national energy intensity. For instance, the transportation sector is a major consumer of energy (Qiao et al., 2024), while factors such as subsidies for electric vehicles, fuel economy standards, and fuel taxation can significantly shape its consumption (Lo, 2014). Thus, energy use in different sectors influence overall national energy intensity in distinct ways. Improvements in management and the introduction of energy-saving technologies have reduced the energy intensity of China's agricultural sector while increasing its GDP share (Hu et al., 2023). Although energy consumption in manufacturing may increase, digitalization has helped reduce energy intensity (Kunkel et al., 2023). Energy intensities in the service sector are declining globally, largely due to structural economic changes and low energy use within the sector, especially as industries in emerging economies upgrade. In the European Union and the UK, tertiary sector energy consumption increased from 2000 to 2019, highlighting the need for continued energy efficiency enhancements (Tzeiranaki et al., 2023).

Higher energy prices and greater capital substitution have driven greater use of renewables, resulting in energy

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intensity reductions in China (B. Chen et al., 2023). Efficient use of energy can lower demand for conventional sources and increase renewable energy uptake, both of which contribute to reductions in energy intensity (Brodny & Tutak, 2022). Additionally, energy intensity declines with the advancement of internet infrastructure, as there is a significant negative relationship between information and communication technology and electricity consumption (Hao & Wu, 2021). Sustainable economic growth is adversely affected by high and medium levels of energy consumption (Altinoz et al., 2020). Increased energy use can result from the “rebound effect”, where efficiency improvements yield less energy savings than anticipated, and the “backfire effect”, in which aggregate productivity is compromised due to higher pollution (Bongers, 2020).

This study adds to the existing literature by examining how the sectoral shares of energy consumption differentially impact the overall energy intensity of economies, focusing on the contrasts between developed and developing countries. Findings show that in developed nations, increased agricultural energy consumption has contributed to reducing energy intensity due to sustainable practices that enhance overall productivity. In developing countries, a rise in industrial energy use has led to higher national energy intensity, while increased adoption of renewable energy sources has helped reduce it.

The remainder of the paper is organized as follows: Section II presents the methodology; Section III outlines the estimation results; and Section IV offers the conclusion.

II. Methodology

A. Framework and hypothesis formulation

Energy intensity can be defined as the total energy used per unit of economic output. Let EI_{it} be the energy intensity of country i at time period t . EI_{it} can be impacted by the share of energy consumption (EC_{it}) of country i at time period t , among other factors, X_{it} .

$$EI_{it} = f(EC_{it}, X_{it}) \quad (1)$$

The share of energy consumption in each sector needs to be analyzed to understand their individual effects on energy intensity. This leads us to formulate our research question as follows: What are the differential impacts of each EC_{jit} (where j represents particular sector of country i) on EI_{it} and how do these impacts differ between developed and developing nations?

For developed nations, we assume that $\frac{\delta EI_{it}}{\delta EC_{it}} < 0$. Energy intensity is assumed to be a decreasing function of energy consumption in developed economies because, as an economy develops, there will be an increase in energy use, but economic output tends to grow at a higher rate, leading to a reduction in energy intensity. This can occur through improved regulations and standards that reduce energy consumption in certain sectors while boosting economic output, as well as direct subsidies and government R&D funding for clean energy investments. Technological advancements also play a crucial role by reducing energy use per unit of output through more efficient manufacturing

processes. A decline in energy intensity implies greater energy efficiency, as less energy is required to produce a unit of economic output. Based on this theoretical framework, we formulate Hypothesis 1 as follows:

Hypothesis 1: With an increase in share of sectoral energy consumption, energy intensity of developed countries will fall.

The above assumption holds for developed nations because their economic output tends to increase at a proportionally higher rate than energy use, resulting in a decline in energy intensity. However, for developing nations, we assume the following: $\frac{\delta EI_{it}}{\delta EC_{it}} > 0$. In these countries, increase in economic output is not sufficient to offset the negative impact of rising energy consumption on energy efficiency. This is largely due to economic growth being closely linked to energy consumption, with policies focused on rapid industrialization and urbanization fueling investments in energy-intensive industries and heightened energy demand for housing, transportation, and infrastructure. The adoption of energy-efficient technologies is less widespread in developing nations, and policies often prioritize immediate energy needs over long-term sustainability. As a result, higher energy consumption is likely to lead to increased energy intensity in developing nations.

Hypothesis 2: With an increase in share of sectoral energy consumption, energy intensity of developing nations will increase.

B. Data and estimation strategy

The data on sectoral shares of energy consumption as a percentage of total energy consumption (EC), which is our main independent variable, was obtained from the OECD database. The data on energy intensity (EI)—the amount of primary energy used per unit of economic output (MJ/\$), which serves as our main dependent variable—was sourced from the International Energy Agency (IEA) and the United Nations Statistics Division (UNSD). We used renewable energy supply (REN) (as a percentage of total energy supply) and population per 1,000 inhabitants (POP), both sourced from the OECD database, as well as the Human Development Index (HDI) from the United Nations Development Programme (UNDP) Human Development Report, as control variables. The trend of the share of value added and share of energy consumption in different sectors for developed and developing countries is presented in Figure 1.

Panel data regression models are employed to analyze the effect of sectoral energy consumption on the energy intensity of nations. The analysis ranges from 2000 to 2022, as energy intensity data was available for this period. Shares of energy consumption in the agriculture, industry, service, and transportation sectors are used as key explanatory variables in separate regressions to avoid multicollinearity. To determine the appropriate estimation method, the Hausman test is applied, which indicates that the fixed effects model is most suitable for these estimations.

The baseline regression equation is as follows

$$EI_{it} = \alpha_0 + \beta_j EC_{jit} + \gamma X_{it} + \varepsilon_{it} \quad (2)$$

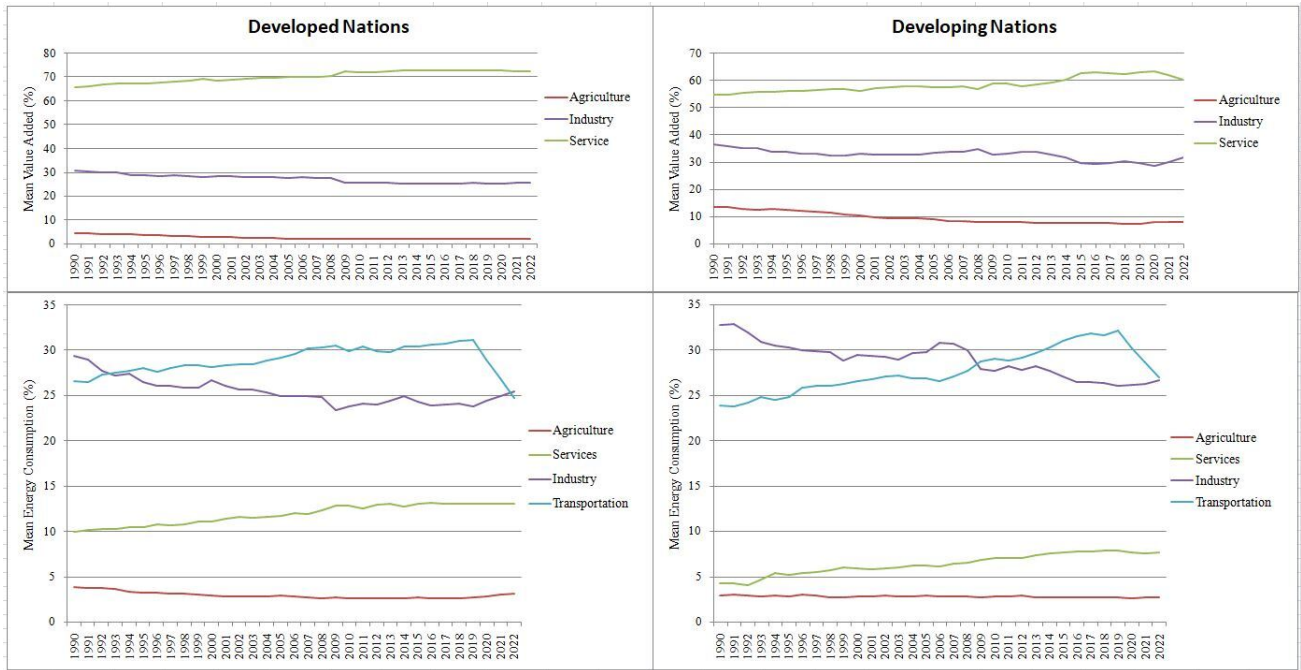


Figure 1. Developed v/s developing nations: Comparison of value added and energy consumption

Notes: The upper panel of the figure presents the average value added by each sector as a percentage of total value added, while the lower panel illustrates the average energy consumption by each sector as a percentage of total energy consumption in both developed and developing countries from 1990 to 2022. Source: Authors' calculations based on the OECD database.

where EI_{it} is the energy intensity of country i at time period t , EC_{jit} are the shares of energy consumption as a percentage of total energy consumption in j = agriculture, industry, service or transportation sector of country i at time period t estimated in separate regressions, X_{it} is a vector of control variables which includes population, HDI and renewable energy supply of country i at time period t and ε_{it} is the error term.

III. Estimation Results

The results of the panel data regression analysis are presented in Table 1. In developed nations, a higher share of energy consumption in the agriculture sector relative to total energy consumption has a negative impact on energy intensity, supporting Hypothesis 1 for the agricultural sector. Specifically, a one percentage point increase in the share of agricultural energy consumption leads to an approximate 0.33 units reduction in the energy intensity of developed economies. This improvement in energy efficiency may be attributed to the adoption of more innovative and efficient technologies within the agricultural sector as economies advance. In developing economies, however, energy consumption in the agricultural sector did not significantly affect energy intensity.

Conversely, while industrial sector energy consumption did not increase energy intensity in developed nations, it had a detrimental effect on the overall energy efficiency of developing nations. In particular, for each percentage point increase in the industrial sector's share of total energy consumption, energy intensity rose by approximately 0.04 units, thereby supporting Hypothesis 2 for the indus-

trial sector. This suggests that industrial energy consumption is a major factor behind higher energy intensity in developing economies and highlights the need for action plans to promote energy-saving innovations and the adoption of less intensive, alternative energy sources in industrial production processes. Chen et al. (2021) indicated that improvements in energy efficiency and a shift to less energy-intensive sectors can help reduce industrial energy consumption.

The share of energy consumption in the service sector, however, did not have a significant impact on the energy intensity of economies. This may be because increases in energy use in the sector are often offset by corresponding increases in economic output, thereby neutralizing the effect on energy intensity. Similarly, the transportation sector's share of energy consumption did not significantly impact energy intensity. This could be due to the increased adoption of electric vehicles, which offsets the impact of higher energy use in this sector by reducing reliance on traditional petrol and diesel fuels.

Our results also show that an increase in renewable energy consumption can help reduce the energy intensity of developing nations, consistent with the findings of Yu et al. (2022). Additionally, higher levels of human development contributed to reductions in energy intensity in both developed and developing nations. Focusing on human development appears to enhance energy efficiency, likely by boosting GDP growth relative to energy consumption, resulting in a decline in the energy intensity of economies.

Table 1. Sectoral impacts on energy intensity

Energy intensity	Agriculture	Industry	Service	Transport
Developed nations	(1)	(2)	(3)	(4)
EC	-0.3309** (0.1473)	0.0581 (0.0516)	-0.0028 (0.0410)	-0.0207 (0.0147)
REN	-0.0333 (0.0197)	-0.0168 (0.0290)	-0.0219 (0.0283)	-0.0238 (0.0282)
POP	-0.00003*** (5.50E-06)	-0.00003*** (5.56E-06)	-0.00003*** (7.03E-06)	-0.00003*** (7.23E-06)
HDI	-15.68*** (2.515)	-16.66*** (2.577)	-16.71*** (2.547)	-16.41*** (2.104)
Constant	20.60***	18.88***	20.59***	20.96***
Observations	713	713	713	713
Groups	31	31	31	31
Developing nations				
EC	-0.1013 (0.0684)	0.0387*** (0.0132)	0.0071 (0.0605)	-0.0362 (0.0275)
REN	-0.0286** (0.0129)	-0.0301** (0.0113)	-0.0265** (0.0128)	-0.0307** (0.0127)
POP	3.64E-06 (3.81E-06)	1.86E-06 (3.95E-06)	3.96E-06 (4.05E-06)	3.70E-06 (3.93E-06)
HDI	-16.80*** (4.211)	-15.32*** (4.244)	-16.90*** (4.608)	-15.40*** (4.441)
Constant	18.21***	15.87***	17.89***	17.99***
Observations	1,491	1,492	1,484	1,491
Groups	65	65	65	65

Notes: “***”, “**”, and “*” represent the 1%, 5%, and 10% significance levels, respectively. Robust standard errors are shown in parentheses. The dependent variable is the energy intensity of the economy, while the main explanatory variables in columns (1), (2), (3), and (4) are energy consumption in agriculture, industry, service, and transportation sectors, respectively.

IV. Conclusion

The analysis of the sectoral impacts of energy consumption on the overall energy intensity of developed nations provides insightful evidence that an increase in the agricultural sector's share of energy consumption leads to reductions in the overall energy intensity of these economies. In the case of developing economies, the industrial sector should be subject to more policy regulations concerning its energy consumption. The adoption of energy-saving targets and policies, such as taxing energy use, should be implemented so that energy consumption in the industrial sector, which is a primary cause of rising energy intensity - can be reduced.

Moreover, digitalization and technological upgrades in the service sector, along with the adoption of electric vehicles, have reduced the use of traditional fuels in the transportation sector. These advances may have offset the impact of higher energy consumption in these sectors on energy intensity, by creating a virtuous cycle where innovations in one sector stimulate growth and efficiency improvements in others, leading to faster GDP growth. Measures to promote renewable energy consumption and to increase taxes on fossil fuel use can also contribute to reducing the energy intensity of developing economies.

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