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Decomposing Aggregate Energy Intensity and Analyzing Sectoral Trends in Algeria (1990–2020)

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Abstract. *This study analyzes aggregate energy intensity (EI) in Algeria from 1990 to 2020 using the Fisher Ideal Index within the Index Decomposition Analysis (IDA) framework. The IDA is conducted with both primary and final energy consumption and is complemented by an analysis of sectoral trends to provide additional insights. The results indicate that the increase in EI is mainly driven by the energy inefficiency effect, while structural changes—particularly the shift toward the tertiary sector—contribute to reducing EI. Differences between the two cases are primarily associated with the energy industries and non-energy use sectors, as well as the industrial and tertiary sectors. These findings suggest that energy efficiency policies should prioritize the transport, residential, energy industries and non-energy use sectors, which remain the most energy-intensive.*

Keywords: *energy efficiency, economic structure, decomposition, sectoral energy intensity*

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Əlcəzairdə məcmu enerji intensivliyinin komponentlərə ayrılması və sektoral meyillərin təhlili (1990–2020)

Layadi Nur əl-Huda

Xülasə. *Bu tədqiqatda İndeks Dekompozisiya Analizi (IDA) çərçivəsində Fişerin İdeal İndeksindən istifadə edilməklə, 1990–2020-ci illər ərzində Əlcəzairdə məcmu enerji intensivliyi (EI) təhlil edilir. IDA həm ilkin, həm də son enerji istehlakı göstəriciləri əsasında aparılır və əlavə məlumatlar əldə etmək məqsədilə sektoral meyillərin təhlili ilə tamamlanır. Nəticələr göstərir ki, enerji intensivliyinin artması əsasən enerji səmərəsizliyi amili ilə şərtlənir; struktur dəyişiklikləri — xüsusilə də xidmət sektoruna (üçüncü sektor) keçid — isə enerji intensivliyinin azalmasına töhfə verir. Bu iki hal arasındakı fərqlər ilk növbədə enerji sənayesi və enerjinin qeyri-enerji məqsədli istifadəsi sektorları, həmçinin sənaye və xidmət sektorları ilə əlaqəlidir. Əldə edilən nəticələr göstərir ki, enerji səmərəliliyi siyasətində ən yüksək enerji intensivliyinə malik olan nəqliyyat, yaşayış, enerji sənayesi və enerjinin qeyri-enerji məqsədli istifadəsi sektorlarına üstünlük verilməlidir.*

Açar sözlər: *enerji səmərəliliyi, iqtisadi struktur, dekompozisiya, sektoral enerji intensivliyi*

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Introduction

The global degradation of environmental quality, the depletion of resources, and the issue of energy are closely linked; as a result, energy has become one of the greatest challenges of the economy. To face the consequences of the increase in energy needs (in the New policies scenario of IEA in 2017, world energy needs will increase by 30% by 2040. Thus, 80% of the total energy consumed in the world is non-renewable origin). Specialists are looking into the problem of controlling energy consumption (Hauet, 2014, p. 77), particularly within the framework of the energy transition, which refers to the shift towards a more sustainable energy system, characterized by reduced reliance on fossil fuels and greater use of renewable energy sources. It essentially builds on two key pillars (Senouci, 2015):

Energy savings (which can be achieved through two complementary approaches: energy efficiency (EE) which refers to the use of less energy to deliver the same service or produce the same amount of useful output, and energy sobriety, which aims to reduce consumption by promoting behavioral changes), and the development of renewable energies.

An economy should aim to consume the least possible amount of energy to produce a unit of GDP. Consequently, the measurement of energy intensity is an indispensable indicator for any energy policy. Energy intensity, defined as the amount of energy used per unit of economic activity or GDP, provides an approximate measure of an economy's energy efficiency, with energy consumption generally aggregated as either final or primary energy (Hauet, 2014). In general, the lower the energy intensity indicator (i.e., the ratio of energy consumption to GDP), the higher the energy efficiency. Thus, high energy intensity reflects the high cost of converting energy into GDP (Mirza & Fatima, 2016).

However, it is important to take into account the diversity of economic activities, since changes in energy efficiency at the sectoral level are not the only factors determining energy intensity trends. Sectoral energy intensity can also vary according to the energy intensity of products (for example, a shift from less energy-intensive products to more energy-intensive ones, or the reverse) within a given sector. Energy intensity can be reduced either by improving efficiency in the use of energy or by shifting away from energy-intensive activities (Metcalf, 2008). Therefore, it is necessary to apply a method of energy intensity decomposition to isolate the impact of efficiency improvements from the effects of activity and sectoral composition changes, in order to provide a more accurate analysis of energy intensity and energy efficiency trends (Marrero & Ramos-Real, 2013).

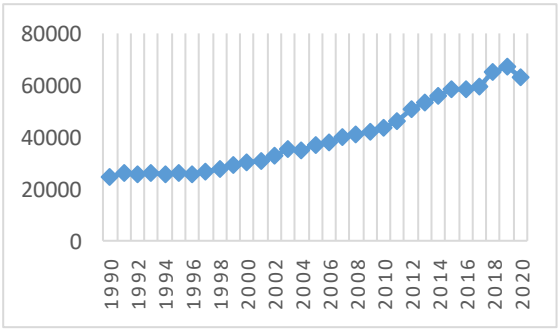


Figure 1

Evolution of national energy consumption in Algeria 1990–2020 (ktoe)

Source. Prepared by the researcher based on national energy balances.

Thus, national consumption (primary energy consumption) in Algeria has seen continuous growth overall, around 67 Mtoe in 2019 and it comes mainly from fossil fuels. Algeria's energy intensity is nearly double the average observed in OECD countries (Senouci, 2015). However, in Algeria, there is a massive potential for energy savings that is expected to continue growing. Indeed, cumulative energy savings could reach around 93 million tons of oil equivalent, including 63 million TOE by 2030. These results would be achieved through the national energy efficiency program, which would also lead to a reduction of 193 million tons of carbon dioxide emissions, as indicated by the Ministry of Energy. This objective forms an integral part of the National Program for the Development of Renewable Energies and Energy Efficiency. This highlights the importance of conducting an in-depth investigation of energy intensity at both the aggregate and sectoral levels in order to propose adequate public policies.

In this regard, our research aims to examine the evolution of aggregate energy intensity in Algeria, using data on primary and final energy consumption, by attributing its variation to the efficiency component and the structural component, between 1990 and 2020. We then intend to compare these findings. In addition, we analyze sectoral energy intensity over the study period to identify the most energy-intensive sectors and provide more in-depth explanations.

The remainder of the paper is structured as follows. Section 1 reviews the existing literature on energy intensity decomposition. Section 2 introduces the data and details the methodological framework adopted. Section 3 presents the empirical findings and provides a discussion of the results, while the final section concludes and offers some policy implications.

1. A brief literature review

We organize in the tables below the main details and results of previous studies:

Table 1
Studies on the decomposition of EI

Reference	Country and period	Method ology	Main results in explaining variations in total EI
(1) Marrero and Ramos-Real , 2013	EU15 countries 1991–2005	LMDI	A positive contribution of 75% through EE improvement and 25% for structural changes in all countries (except Austria, both had a similar contribution)
(2) Mirza & Fatima, 2016	Pakistan, 1980-2009	Fisher	There is energy inefficiency, and a small contribution from the structural component (8%) in reducing the overall EI.
(3) Ben Hammamia et al., 2014	Tunisia 1990-2008	Fisher	The efficiency component has an EI reduction effect of 56%, and 44% for the structural component on average
(4) Metcalf, 2008	US, 1970-2003	Fisher index	The effect of improved energy efficiency is the main contributor
(5) Nugraha, 2019	Indonesia 1984-2015	LMDI	Efficiency effect reduced EI by 69.07% vs. 5% for structure effect
(6) Tenaw, 2021	Ethiopia 1990–2017	LMDI-I	A significant contribution of the intensity effect in the variation of EI.
(7) Robaina et al., 2019	Portugal 1995-2015	LMDI	The reduction in EI is related to the efficiency component, structural changes have a negative effect.
(8) Zhang et al., 2019	Shanxi Province (2000-2015)	M-LMDI-II	Both effects contribute to the reduction of the EI index (21.74% for sectoral EI and 24.29% for the structure effect)
(9) Voigt et al., 2014	40 major economies 1995-2007	LMDI	In the majority of countries, the effect of structural change has a lesser impact on improving EI.
(10) Ullah et al., 2014	Pakistan 1972-2011	Fisher	The increase in EI was caused by the efficiency effect, where inefficiencies in electricity consumption played the primary role, followed by those in natural gas.
(11) Deichmann et al., 2018	137 countries (1990–2014)	Fisher	The contribution of the structural component to the reduction of the EI is more important (this is valid at all income levels)
(12) Oteng-Abayie et al., 2023	Ghana, 2000–2020	LMDI I	Energy intensity in Ghana is largely attributable to structural effects

Source. Prepared by the author.

Several analytical methods exist for analyzing energy demand, including decomposition analysis. This approach examines changes in energy demand arising from a number of factors (particularly changes in economic activity, changes in sectoral energy efficiency, and changes in the economic structure). This is achieved by analysing changes in energy consumption, and analysing changes in energy intensity. The literature has largely emphasized energy intensity and its decomposition; as shown in Table 1, many

researchers have used various decomposition methods to analyze energy intensity by quantifying the impact of different factors and their contribution to the overall change.

Decomposition analyses have been conducted in several ways. Some authors carried out this decomposition exclusively at the national level (3, 2, 5, 7, 6, 12), while others extended the analysis to multiple levels or to the case of several countries (8, 11, 9). Similarly, study (1) addressed the case of 15 European Union countries.

It is worth noting that some analyses simultaneously consider the national and multi-level perspectives. For example, study (4) decomposed the EI of the United States at the national level first, then moved on to an analysis at the level of individual states.

Furthermore, study (10) focused on decomposing energy intensity by product (oil, gas, and electricity) to provide more detailed and in-depth analysis related to overall energy intensity.

Based on this section of the literature review, it can be concluded that decomposition analysis of EI has generated diverse results. Some authors have shown that the component with the dominant impact or contribution is efficiency (3, 1, 4, 5, 7, 6, and 9).

Conversely, in other empirical studies, the structural component has exerted a stronger influence on EI variation (12, 11, 2, 8). However, some authors have reached the conclusion that both efficiency and structural effects exert a similar impact, as in the case of Austria reported by (1).

To the best of our knowledge, the only existing study that applies a decomposition approach to Algeria's energy intensity is that of Layadi and Senouci (2022), which is limited to national energy intensity. This study contributes to the literature by addressing this gap and providing a comprehensive analysis of Algeria's energy intensity at both the aggregate (using primary and final consumption) and sectoral levels.

2. Data and methodology

This section presents the data types and sources, followed by a detailed explanation of the study methodology.

2.1. Type and source of data

The energy intensity index can be decomposed into the two components previously identified, provided that sectors are constructed to encompass the entirety of energy consumption without overlap, and that a measure of economic activity is available for each sector to enable the calculation of energy intensity. Importantly, sectoral activity measures need not correspond directly to GDP, as they may be expressed in different units (Metcalf, 2008).

In our case, the six energy-consuming sectors under consideration are: residential, transport, industry, agriculture, tertiary, and the energy industries and non-energy use sector. The annual dataset for the empirical analysis covers the period 1990–2020 and consists of the following:

- Data on aggregate output, proxied by GDP, and sectoral output, proxied by value added (VA) for all sectors except:

- Residential sector, where household consumption expenditure is used as a proxy, as it was argued that personal consumption expenditures provide a better proxy and key driver of residential energy demand than disposable income, since the latter is affected by savings.
- Transport sector, where average distance traveled is used as a measure of economic activity, in line with certain studies in which vehicle miles traveled were used as a measure in this context (Metcalf, 2008).
- Energy demand data, including total annual energy consumption and sectoral energy consumption.

The definitions and sources of the variables described above are summarized in the following table.

Table 2
Variable definitions and sources

Variables	Definition	Source
Energy demand		
Aggregate	Total consumption (ktoe)	National Energy Balance (Ministry of Energy)
Sectors: industry, tertiary, agriculture, residential, transportation, and energy industries and non-energy use sector	Energy consumption (ktoe)	National Energy Balance + APRUE
Economic activity		
Aggregate	Gross domestic product (GDP at constant pricess in national currency, including hydrocarbons; 2010 MDA)	NSO
Industry, tertiary, agriculture, energy industries and non-energy use sectors	Value added (at constant pricess in MDA, 2010 as a base year)	Ministry of Finance + economic accounts published by NSO
Transport sector	Average distance traveled (km/year)	APRUE, from Ministry of Transport data
Residential sector	Private household consumption (in constant national currency in MDA, 2010 as a base year)	NSO + APRUE

Source. Prepared by the author.

2.2. Decomposition method

Many studies adopt the decomposition method in order to highlight the different factors that contribute to the EI variation. Among these decomposition techniques, the Index Decomposition Analysis (IDA) method and the Structural Decomposition Analysis (SDA) method. In this publication, we have relied on one of the best-known IDA-based approaches: Fisher's ideal index, which has advantageous properties such as the ability to provide an exact decomposition of the overall EI into an efficiency index (eff) and an activity index (act) without residue (Metcalf, 2008). Under this approach, the energy intensity (e_t) can be represented as a function of two components: the structural effect and the sectoral energy efficiency effect:

$$e_t = \frac{E_t}{Y_t} = \sum_j \frac{E_{jt}}{y_{jt}} \frac{y_{jt}}{Y_t} = \sum_j e_{jt} s_{jt}$$

E_t the aggregate energy consumption, E_{jt} the sector energy consumption, Y_t GDP, y_{jt} measure of sectoral economic activity in year. Thus, the total EI e_t is a function of the sectoral energy efficiency (e_{jt}) and of the activity linked to the sector (the share of each sector in the total value added) (s_{jt}).

The EI index (It) is represented as follows:

$$\text{It = and / =} e_0 \frac{\sum_j e_{jt} s_{jt}}{\sum_j e_{j0} s_{j0}}$$

$e_0$is the total energy intensity of the base year 1990 in our case.

To construct Fisher's ideal index, which provides a perfect decomposition without residuals, we will calculate the geometric mean of the Laspeyres indices (which takes the values of the base year as weights) and Paasche (takes the values of the current year as weights) for the two components:

$$L_t^{eff} = \frac{\sum_j e_{jt} s_{j0}}{\sum_j e_{j0} s_{j0}} P_t^{act} = \frac{\sum_j e_{jt} s_{jt}}{\sum_j e_{jt} s_{j0}}$$
$$P_t^{eff} = \frac{\sum_j e_{jt} s_{jt}}{\sum_j e_{j0} s_{jt}} L_t^{act} = \frac{\sum_j e_{j0} s_{jt}}{\sum_j e_{j0} s_{j0}}$$

Thus the Fisher index is given as follows:

$$F_t^{eff} = \sqrt{L_t^{eff} P_t^{eff}} \; and$$
$$F_t^{act} = \sqrt{L_t^{act} P_t^{act}}$$

$$\frac{e_t}{e_0} = I_t = F_t^{eff} F_t^{act}$$

3. Results and Discussion

3.1. Results using primary energy consumption and Hydrocarbon GDP

During the specified period, Algeria experienced a fairly steady upward trend in energy intensity (Layadi & Senouci, 2022). The underlying drivers of these changes are illustrated in Figure 2, which presents the results of the energy intensity decomposition using index effects, based on 1990.

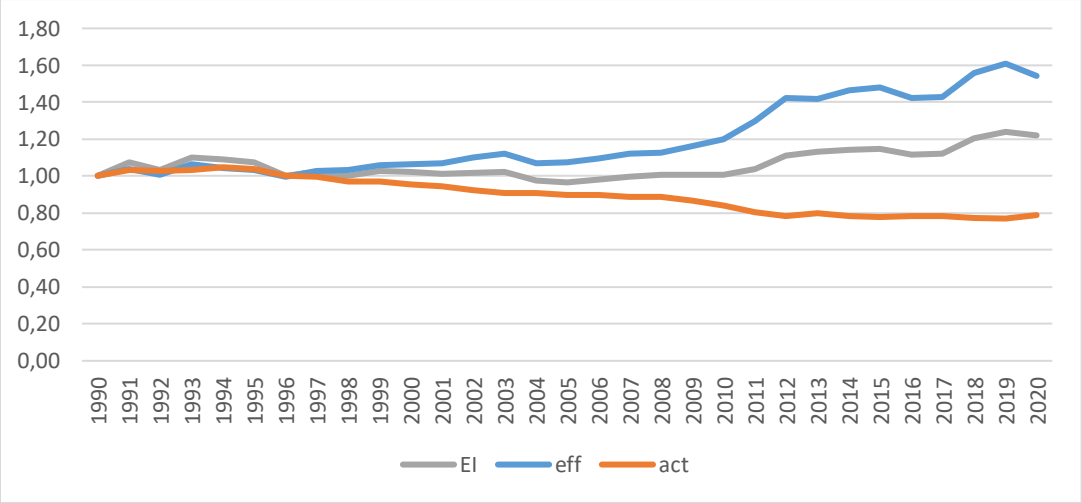


Figure 2
Decomposition of EI in Algeria (1990 base year)

Source. Developed by the author.

For the analysis of the variation in the aggregate energy intensity index and its specific components (using 1990 as the reference year), an index greater than 1 indicates an increase in the effect.

Overall, aggregate energy intensity steadily increased over the study period: in 2019, the index reached 124% of its 1990 level (a rise of 24%), before declining to 122% in 2020. This pattern reflects an increase in energy consumption up to 2019, followed by a reduction in 2020, most likely attributable to the impact of the COVID-19 pandemic. By contrast, between 2003 and 2007, the EI index remained below 1.

On average over the entire period, the index was 6% higher than its base-year level.

The upward trend in aggregate energy intensity and its efficiency component has shown a strong alignment. As illustrated, the overall variation in EI is largely driven by the efficiency effect, which played a key role in the increase of aggregate EI, reaching 161% of its 1990 level in 2019 and 154% in 2020, before a decline in the EI index from 123% to 121% during the COVID-19 year. This indicates that, for most of the period, energy inefficiency prevailed in the economy. In other words, if the structural composition of the economy had remained unchanged, energy inefficiencies within specific activities would have resulted in a deterioration of EI by 61% in 2019 and 54% in 2020 compared to its 1990 level. The only exceptions were during 1994–1996 and 2003–2007, when energy efficiency exerted a reducing effect on EI, particularly in 2004–2006, when the index fell below unity, reaching 97% of its 1990 level in 2004 and 2005, reflecting a slight improvement in EI.

In contrast, the structural effect had a less significant and negative impact on the variation of energy intensity (EI) since 1996. Specifically, the activity component contributed to a reduction in aggregate EI from 1996 until 2019, before exerting a slightly increasing effect in 2020 (the index rose from 77% of its initial level in 2019 to 79% in 2020, representing a 2% difference).

Overall, the increase in EI at the aggregate level of the economy is strongly associated with the efficiency component, which accounts for 96.4% of the total rise in EI. In other words, the deterioration of sectoral energy efficiency is the predominant factor explaining the variation in aggregate EI.

Thus, we conclude that energy use in Algeria has not been efficient. The efficiency effect emerges as the most decisive factor in this relationship, suggesting that efforts to reduce total EI must primarily target the sectoral level. By contrast, changes in the structural composition of the economy did not lead to a considerable increase in EI. Nevertheless, they did contribute, to some extent, to reducing the overall energy intensity of the country.

3.2. Results using final energy consumption and non-hydrocarbon GDP

Figure 3 shows the results of the EI decomposition in the case of considering only final consumption sectors, using index effects, based on the year 1990.

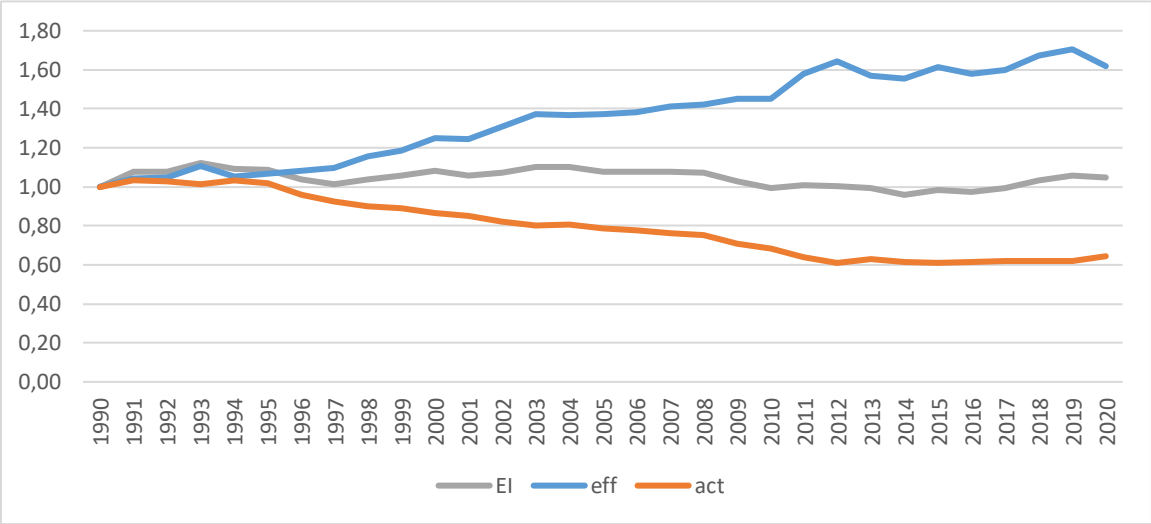


Figure 3

Decomposition of the final EI in Algeria (1990 base year)

Source. Prepared by the author.

Taking 1990 as the base year, the energy intensity (EI) index in this case reached 105% in 2019 and 106% in 2020 relative to its initial level. Over the entire period, starting from the base year, the index was on average 4.48% higher than that of 1990.

The efficiency index stood at 171% and 162% in 2019 and 2020, respectively, compared to its 1990 level. For the activity index, the corresponding values were 62% and 65% (indicating a 3% increase between 2019 and 2020). Thus, in 2020, the efficiency index was 62% higher and the activity index 35% lower than their respective levels in 1990.

The highest value recorded for the efficiency index was 1.71 in 2019, while the activity index peaked at 1.03 in 1994. Hence, if the structural effect had remained constant at its 1990 level across all sectors, energy intensity would have increased by 71% in 2019. The structural effect, however, exerted a negative influence, thereby contributing overall to a reduction in aggregate intensity during the period 1990–2019, and only played a negligible augmenting role thereafter (2019–2020).

The EI index remained above its base-year value for nearly the entire period, as did the efficiency index, whereas the activity index consistently stayed below its initial level. Consequently, the trajectory of the EI index can be seen as being driven much more by efficiency than by activity.

Our results therefore indicate that the rise in EI during the period can largely be attributed to the efficiency component, which accounted for 95.4% of the total variations in EI.

By comparing with the previous graph, it is evident that the rate of increase in EI in the first case is stronger than in the second case. However, throughout the period, the EI index in both cases followed the same overall trend, except between 2003 and 2007, when the indices moved in opposite directions. In the second case (considering only final consumption sectors), the EI index showed an upward trend and remained above unity, whereas in the first case (considering primary energy and thus all sectors), it remained relatively stable, slightly below its initial level.

In terms of energy balance decomposition and methodology, national energy consumption is defined as follows:

National energy consumption = Final consumption (sectors concerned: industry, transport, households, and others) + Consumption by energy industries and non-energy uses (Senouci, 2015).

Accordingly, this difference can be attributed to the energy and non-energy industries sector. The subsequent analysis further confirms and clarifies this finding.

3.3. Trends in energy intensity by sector

For a more in-depth explanation and analysis of the increase in EI, we present the following figure.

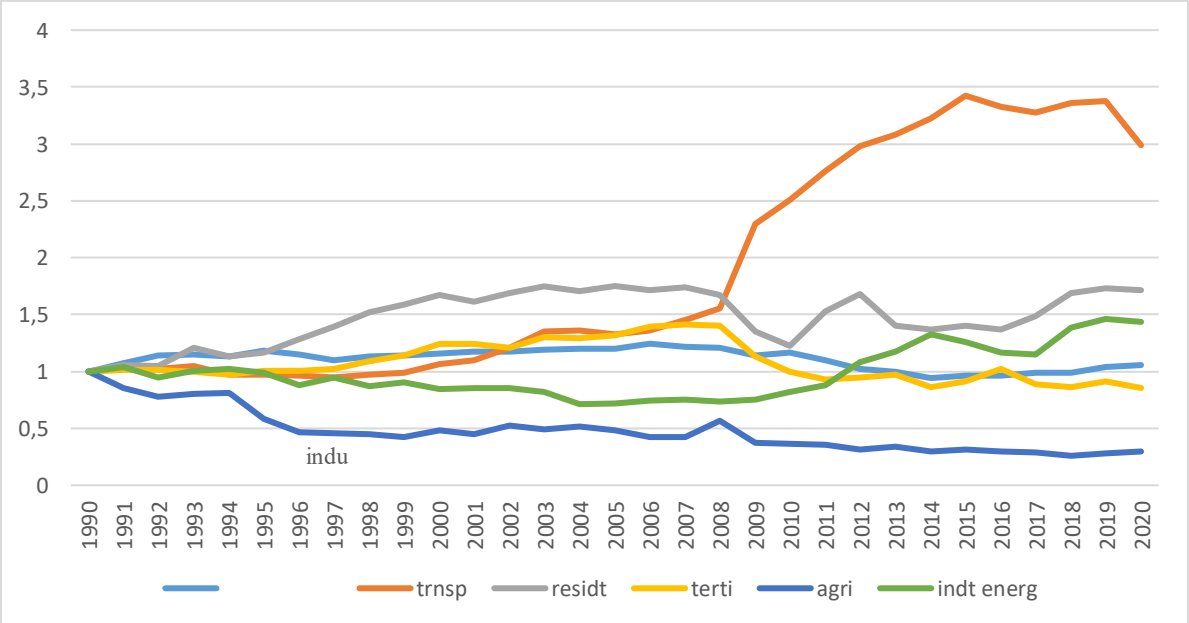


Figure 4

Trends in energy intensity by sectors compared to the 1990 level in Algeria

Source. Prepared by the author.

Thus, the figure shows the evolution of the sectoral energy intensity of all the sectors considered during the study period. Starting in 2008, the transport sector experienced a sharp rise in EI, surpassing the residential sector, which had previously been the most energy-intensive (its index reached 172% of the base-year level in 2020). Before 2008, this trend in the residential sector could be linked to the

widespread but relatively inefficient use of appliances such as cooking stoves and lighting. After 2008, however, the growth of residential EI slowed slightly, which may be attributed to the adoption of more efficient household appliances. It is worth noting that in some years prior to 2008, residential EI had even reached 175% of its 1990 level.

Conversely, the transport sector's energy intensity continued to rise until 2015, reaching 342% of its 1990 level. Between 2016 and 2019, it declined moderately, reflecting the increase in fuel prices observed during this period. A sharper reduction followed in 2019–2020, attributable to the contraction in transport activity during the COVID-19 pandemic, with the index falling to 337% in 2019 and 298% of its 1990 level in 2020.

Between 2006 and 2014, the industrial sector's EI declined before rising again during 2014–2020, reaching 104% in 2019 and 106% in 2020 relative to its base year. The agricultural sector, by contrast, consistently displayed the lowest and steadily declining EI throughout the period.

Between 1996 and 2010, the energy and non-energy industries sector was the only sector that experienced a decline in energy intensity, particularly between 2003 and 2007. All other sectors showed an increase with indices above unity (except for the agriculture sector, which consistently had an EI index below 1). This explains why the reduced EI index values observed in the previous analyses (the first case) can be attributed to the decline in EI within the energy and non-energy industries sector. This decline may be linked to the growth of this sector's share in GDP (hydrocarbon value added) achieved during the same period, which likely contributed to improving its EI ratio.

Thus, within this comparison, and starting from 2010, the energy and non-energy industries sector surpassed both the industrial and tertiary sectors in terms of energy intensity (reaching 143% of its 1990 level, in 2020). In contrast, the tertiary sector experienced a decline in EI, whereas it had remained above unity prior to 2010 (its intensity index in 2020 stood at 85% of its 1990 level). It can therefore be stated that during the period 2010–2016, the increase in EI observed in the first graph was mainly driven by the energy and non-energy industries sector, while the slight decrease in the EI index during the same period in the second graph can be explained by the variations in EI within the tertiary and industrial sectors. From 2017 onwards, however, an increase is observed in both graphs, attributable to the continued rise across all sectors.

Overall, the transport sector, the residential sector, and the energy industries and non-energy use sector were, in that order, the most energy-intensive. They were the main contributors to the increase in Algeria's national energy intensity during the study period, in addition to the industrial sector, whose role was comparatively less significant, particularly toward the end of the period (with sectoral indices exceeding 1, namely 2.99%, 1.71%, 1.43%, and 1.05%, respectively). By contrast, the tertiary sector, and especially the agricultural sector, remained the least energy-intensive.

Conclusion

In this study, we examined the respective contributions of changes in energy efficiency and in economic structure to the overall variation in energy intensity in Algeria, using national and final energy consumption. To achieve this, we decomposed aggregate energy intensity using the Index Decomposition Analysis (IDA), based on Fisher's ideal index, which separates energy intensity into two components: the efficiency index and the activity index.

Our findings show that a large share of the increase in energy intensity over time is associated with inefficient energy use. In other words, the amount of energy consumed per unit of output has risen over the period 1990–2020. By contrast, the activity effect had a negative impact: the gradual shift of the economy towards less energy-intensive activities has contributed to reducing energy intensity, as the structure of the economy has increasingly favored less energy-demanding sectors (the Algerian economy has undergone a process of tertiarization).

More specifically, when considering total national energy consumption (primary energy), about 96.4% of the increase in energy intensity since 1990 can be attributed to the deterioration of energy efficiency. This share decreases slightly to 95.4% when only final energy consumption is considered. Hence, the variation of the EI index in both cases follows a similar trend, except during the periods 2003–2007 and 2010–2016. The difference can be attributed to the EI of the energy industries and non-energy use sector, which declined in the first period—explaining the lower EI index values (index below 1) observed in the analysis using primary energy consumption—and increased in the second period, surpassing the tertiary and industrial sectors, both of which fell below an intensity index value of 1 over the same interval. Consequently, the increase in EI observed in the first case (using primary energy consumption) was mainly driven by the energy and non-energy industries sector, while the slight decrease in the EI index in the second case (using final energy consumption) can be explained by variations in the tertiary and industrial sectors. Beyond this, in the remainder of the period, the rise in energy intensity in both cases can be primarily explained by the continued growth across all sectors, particularly the residential and transport sectors.

These results suggest that Algeria should prioritize reducing energy intensity in key sectors, particularly by improving their energy efficiency. In this regard, the transport and residential sectors remain the most energy-intensive, followed by the energy industries and non-energy use sector. Policies and measures targeting these sectors are likely to have the strongest impact on lowering national energy intensity.

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