Global Energy Efficiency, Economic Drivers, and CO2 Mitigation

A DUAL PERSPECTIVE: GLOBAL TRENDS AND UK HOUSEHOLDS

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Introduction:

In the context of increasing global concern over CO2 emissions and climate change, energy efficiency has emerged as an important metric in economic and environmental policy analysis. Energy efficiency is not just a technical metric – it is the reflection of how effective the modern economy's function.

This project will investigate the global energy efficiency trends and its effects on CO2 emissions. Throughout the lens of economic analysis, the project aims to answer the question – **can policies aiming to increase energy efficiency assist the environment?**

At the global level, the research paper will analyse the changes, determinants and trends of energy efficiency: perform a cross-country comparison between a sample of developed and developing countries. Furthermore, it will look at the relationship between CO2 emissions and energy efficiency.

Simultaneously, the project zooms in on households of UK and Wales, to analyse regional differences in energy efficiency and environmental impact.

Combining rigorous statistical tools, dynamic visualizations, and spatial analysis, this research aims to provide policymakers with policies that transition people to a low-carbon, high-efficiency, green future.

Data Analysis and Visualisation:

To investigate the relationship between energy efficiency, macroeconomic factors and CO2 emissions, this project combines many different datasets for both global and micro-level analysis. First part of the discussion will focus on the global trends:

Global Trends in Energy Efficiency and CO_2 Emissions

Table 1: First five observations of the dataset

Country	*Year*	*RGDP (millions$)*	*CO2 Emissions (MMTCD)*	*Energy Consumption (Quad Btu)*	*EEI (Quad/millions$)*
Albania	1980	9974	9.6	0.163	1.6×10^{-5}
Algeria	1980	242,874	46.0	0.781	0.3×10^{-5}
Angola	1980	30,380	3.4	0.06	0.2×10^{-5}
Argentina	1980	130,205	93.0	1.71	1.3×10^{-5}
Australia	1980	349,085	221.0	2.99	0.9×10^{-5}

(The table above includes only relevant variables; the actual dataset has more columns)

Energy Efficiency Index(EEI) is calculated as a ratio of Energy consumption and RGDP. The former is measured in quads of electricity and the latter in millions of dollars. So, the EEI can be thought of as number of quads of electricity needed to produce 1million US dollars of output. To avoid confusion, It is essential to note that **low EEI implies high efficiency**.

Evolution of Energy Efficiency Index Over Time:

Over the sample period (2000 - 2020) the energy efficiency index has decreased for most countries, meaning that they produce more output per one unit of energy. However, the trends in energy efficiency have not been the same across the world. Notably, the post-soviet countries saw a significant decrease in the EEI. Furthermore, it seems that trends for developing and developed countries are fundamentally different.

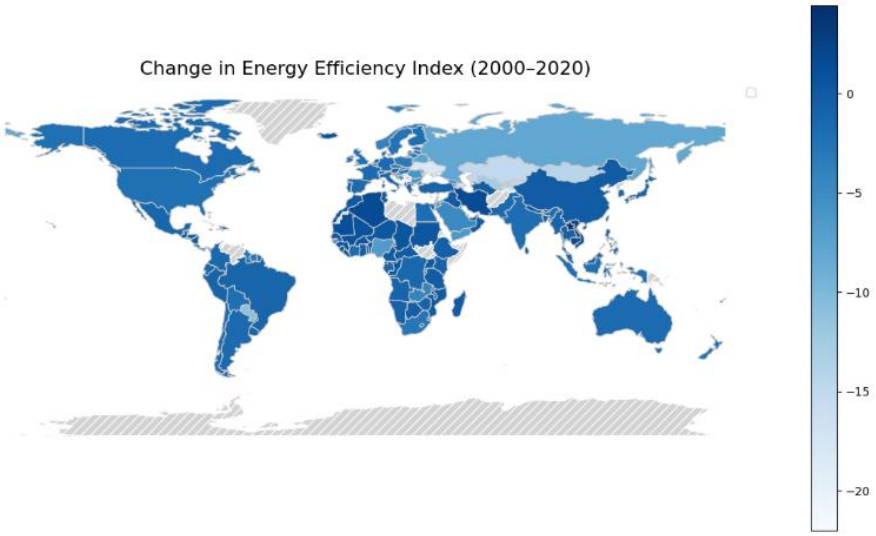

Figure 1: Percentage Change in Energy Efficiency Index(2000-2020), the colour scale represents the percentage change in EEI. Lighter shade of blue represents significant decrease in EEI.

Why Post-Soviet countries have lower EEI?

Soviet Legacy of Energy Wastefulness:

Post-Soviet countries inherited the energy technologies of the soviet union. As noted in Sinyak (1991), *"The Soviet energy system is characterized by low efficiency and high per capita energy consumption,"*, reflecting the legacy of energy-intensive industrial structures and limited incentives for conservation under central planning.

Rapid economic growth:

The following collapse of the Soviet Union may have allowed countries to adopt a more advanced, energy-efficient technologies significantly decreasing the EEI. Additionally, post-soviet countries experienced a significant growth in GDP driving the EEI down.

Comparison of Developed and Developing Countries:

Comparing trends for a sample of developing countries and developed countries, we notice that developed countries tend to have linearly decreasing EEI while developing countries have decreasing but more complex, non-linear relationship.

Developed countries exhibit a stable linear improvement over the sample period, with the EEI halving – or, equivalently energy efficiency doubling. One plausible explanation of the linear improvement may be linearity of RGDP growth in developed countries.

Developing countries show a more volatile, non-linear trend, with EEI fluctuating about 5 and then decreasing rapidly from 2005. Post 2010, the EEI stabilizes and starts oscillating about 4. This may be due to the RGDP and Energy Consumption of developing countries growing at similar rates on early stages of modernization. Then, potentially due to institutional and structural changes the economy adopts newer, more energy efficient technologies.

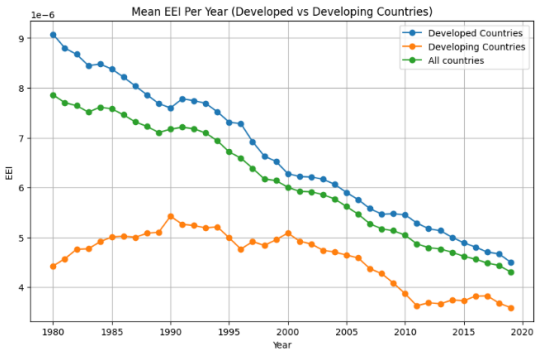

Figure 2: Average EEI (Quad/USD) for selected developed (UK, Canada, US, Japan) and developing (India, Brazil, China, Pakistan) countries, 2000–2022.

The Y-axis is divided by a factor of a million. The graph represents aggregated means over years for a sample of developed and developing countries. The green line represents all countries in the sample aggregated over years. (Taking different countries' sample does not yield drastic changes)

Why do developing countries have lower EEI?

Although developing countries often appear to have lower Energy Efficiency Index (EEI) values, this does not accurately reflect energy efficiency of the economy.

1. First, data quality and consistency in many developing countries may be limited, especially in light sectors of economy(agriculture), leading to potential underestimation of energy use.
2. Second, many developing countries rely on the light industry such as agriculture which produce more output with lower energy consumption. This stands in contrast to developed countries, where economy is often more reliant on energy-intensive industries.
3. Third, limited access to energy infrastructure in developing countries results in overall energy consumption being constrained. As a result, these nations are forced to use less energy, which inflates energy efficiency.

UK EEI compared to sample of developed and developing countries:

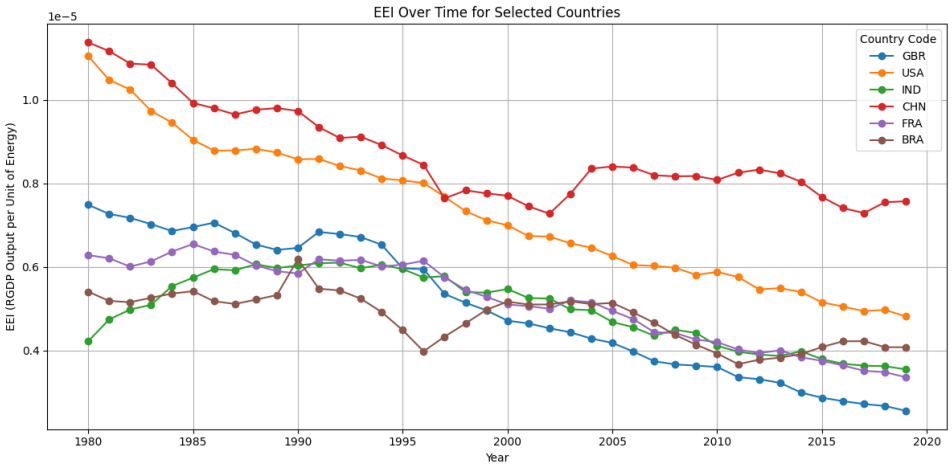

Figure 3: Cross-country comparison of EEI trends, the axes and scaling are exactly the same as in Figure 1. Each coloured line represents EEI trajectory for different countries within the sample.

Key observations from the graph:

EEI seems to be homogeneous among developing and developed countries:

Developed countries on the graph like USA, France and UK show a steady, linear improvement in energy efficiency while developing countries like India, China and Brazil show a more volatile trend. This is consistent with trends exhibited in figure 2.

UK as the leader in energy efficiency:

Notably, post-2010, the UK(represented by the blue line) achieved the lowest EEI in the sample. This may suggest that UK implements effective policies to battle energy inefficiencies.

National-Level Dynamics:

While analysis of global trends in energy-efficiency helps understand broader patterns. It is essential to consider these dynamics on a national levels. Particularly in the UK where EEI was consistently the lowest for a decade among the countries in the sample.

Regional Heterogeneity in England and Wales:

To analyse regional trends in England and Wales we will look at the median energy efficiency and environmental impact scores across years 2020 and 2021.

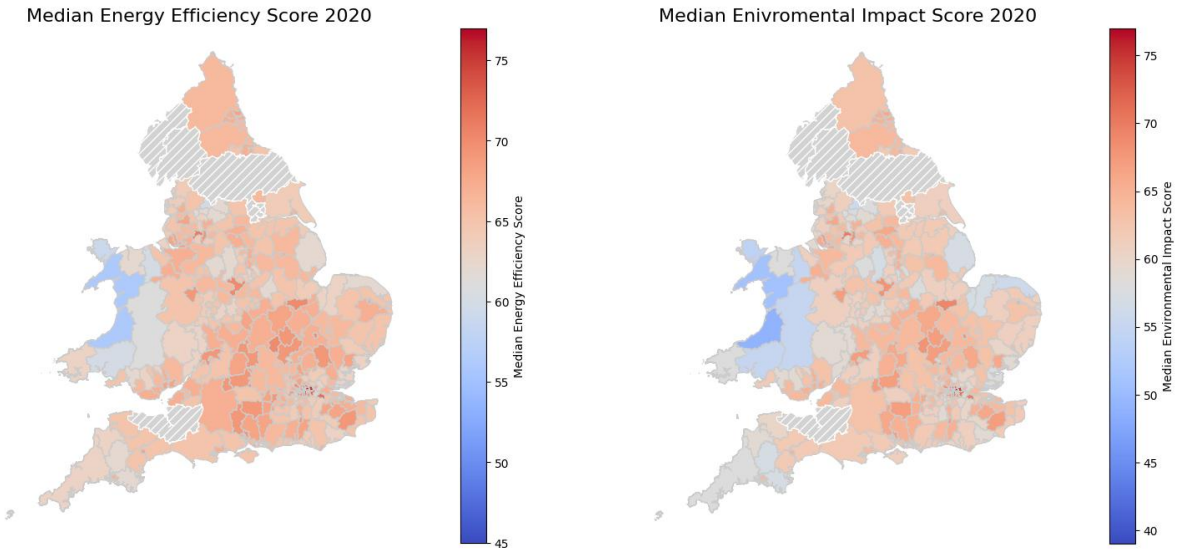

Figure 4: Median Energy Efficiency and Environmental Impact Scores in England and Wales in March 2020. Red indicates a higher energy efficiency(environmental impact) score.

Generally, It seems that UK generally has much higher energy efficiency than Wales.

Furthermore, it seems that environmental score and energy efficiency score are very similar; the correlation coefficient is 0.98.

Why is there regional heterogeneity among England and Wales?

1. **Age of Housing Stock:** In regions in the United Kingdom such as Wales, dwelling houses were generally built earlier than newer residential developments in the southeast of England. In the last twenty years, manufacturers in the construction industry have developed more effective materials and technology in order to satisfy new EPC regulations, and builders have had to become more knowledgeable about residential energy efficiency due to stricter building regulations.
2. **Urban vs. Rural Composition**: Wales has a higher proportion of rural and detached properties, which are typically larger in size relative to properties in England and thus they are harder to insulate effectively.
3. **Adoption of Energy Efficient Technologies**: England is generally more developed than Wales, specifically areas like London. Thus, more developed England adopts newer technologies faster than Wales.

Why are environmental score and energy efficiency score so similar?

- **Overlapping metrics:** Both energy efficiency and environmental impact are derived from the same factors. Generally, if a building is not energy efficient then we would expect it to have lower CO2 emissions and thus better environmental impact score. Thus, we could consider a plausible explanation to be that higher energy efficiency leads to better environmental impact.

Have there been an improvement in energy efficiency score?

The change in Energy Efficiency Index seems to be relatively small. However, it seems that Wales experienced a significant improvement. The decline in energy efficiency index seems to be mostly insignificant. Generally, most places in England and Wales saw a steady increase in energy efficiency.

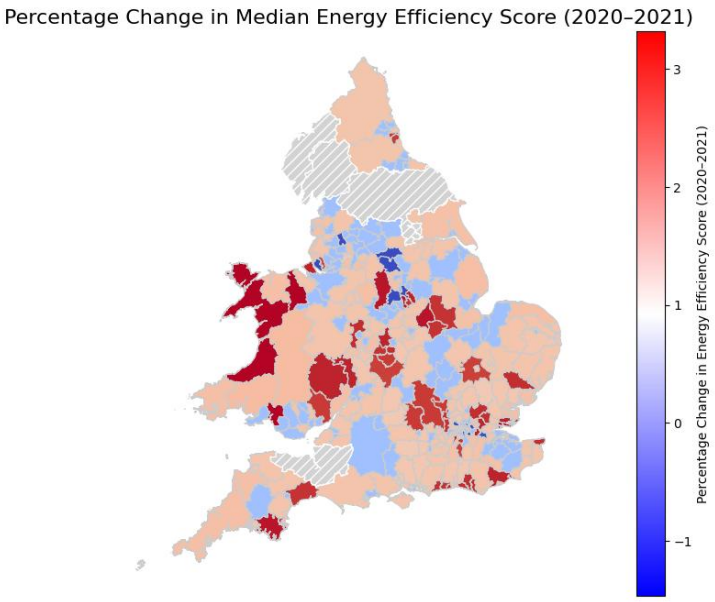

Figure 5: Percentage Change in Median Energy Efficiency Score from 2020 to 2021.

What factors could have led to this improvement?

In United Kingdom there are many policies and regulations aimed to improve energy efficiency of the economy. However, the EEI measures how well insulated the housing units are; thus, the improvements may be explained by retrofit.

Retrofit – an improvement work aimed to increase energy efficiency of a building. For example:

- Improved insulation of the housing units
- Implementation of more energy efficient lighting
- Integration of renewable energy (setting a solar panel)
- Seal of air leaks

Regression Analysis:

Second part of this analysis will focus less on the visualization and presentation of trends and more on the driving factors behind EEI and CO2. Specifically, we will focus on finding factors that drive energy efficiency.

Justification for the model

$$\log(EEI_{i,t}) = \beta_1 \log(hc_{i,t}) + \beta_2 \log(RE_{i,t}) + \eta_i + \eta_t + e_{i,t}$$

Equation 1: regression model. η_i and η_t represent entity and time effects respectively.

Energy efficiency index is derived from ratio of energy consumption and real GDP. This means that we could potentially use variables that explain RGDP to explain EEI.

The variables of choice are human capital index and renewable energy as percentage of total energy produced in a country.

All variables were log transformed. This was done so that the beta coefficients can be interpreted as elasticities.

We account for time and for country-specific trends to extract the effect of regressors on energy efficiency index.

Variables	*Parameters*	*Estimates*
Human Capital (in log)	β_1	-0.245^{***} (0.046)
Renewable Energy as percentage of GDP	β_2	-0.888^{***} (0.222)
	R^2	0.958

Table 2: Results of the regression.

Results:

- **Statistically significant and negative β_1:**

This means that a 1% increase in human capital contributes to -0.24% decrease in energy efficiency index; note, that lower EEI corresponds to a more energy efficient economy.

- **Statistically significant and negative β_2:**

This suggests that if the percentage of renewable energy in the country increases by 1% then the EEI improves by about 0.9%.

- **High R-squared:**

This is most likely due to regression accounting for entity and time effects, improving the fit.

Conclusion and Policy Recommendations:

The analysis of the EEI has revealed several important insights into the structure and development patterns of EEI.

Generally, throughout the years most countries saw an improvement in energy efficiency; especially, among the post-soviet countries that adopted more energy-efficient technologies and institutions, contributing to significant improvements in EEI.

In contrast, developed countries like USA, Canada or UK experienced a steady linear improvement in energy efficiency, with UK emerging as the leader in the past decade.

A more profound analysis revealed the regional heterogeneity of energy efficiency; in UK, there is a significant difference in energy efficiency trends between England and Wales. This may suggest that regional factors like urbanization play an important role in the energy efficiency trends.

Additionally, the analysis identified key economic factors contributing to changes in EEI – human capital and renewable energy.

From a policy perspective, the findings provide few recommendations for policymakers:

Investment into human capital: a more educated workforce allows a country to produce wealth using less energy, improving the EEI

Taxation aimed to incentivize investments into renewable energy: governments should be prioritizing investment into renewable energy sources while simultaneously implementing taxes on non-renewable energy sources.

Retrofitting the infrastructure: government programs aimed at upgrading old buildings to improve insulation, reduce excessive energy consumption, driving the energy efficiency up.

Targeted regional development: policymakers should implement programs (for instance, retrofit) aimed to decrease regional differences.

References:

Sinyak, Yury. "USSR: Energy efficiency and prospects." *Energy* 16.5 (1991): 791-815.

Data outside the one provided on Moodle was downloaded from World Bank data:

Human Capital Index – available at https://data.worldbank.org/indicator/HD.HCI.OVRL

Renewable energy consumption as percentage of total final energy consumption – available at https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS