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Reaching (Beyond) the Frontier: Energy Efficiency in Europe

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Reaching (Beyond) the Frontier: Energy Efficiency in Europe

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Abstract

The world is not decarbonizing fast enough, with global warming on track to reach as much as 4°C over the next century absent a global green transition. Policymakers in Europe—and beyond—still have an opportunity both to achieve net zero emissions by 2050 and to strengthen economic prospects by increasing energy efficiency, along with changing the energy mix from fossil fuels to renewables. In this paper, we assess energy efficiency (or intensity) in a panel of 38 European countries over the period 1980–2021 by using the stochastic frontier analysis and obtain statistically significant and intuitive results. We have two key findings. First, price signals, including through the introduction of a carbon tax and the removal of fossil fuel subsidies, are critical for energy efficiency, as consumers respond to changes in energy prices. Second, stronger environmental policies and institutions generate unambiguous improvements in energy efficiency by inducing investment in energy efficient equipment and buildings and nudging consumers for energy conservation. These results—robust to alternative specifications and methods—have important policy implications for green growth with higher energy efficiency.

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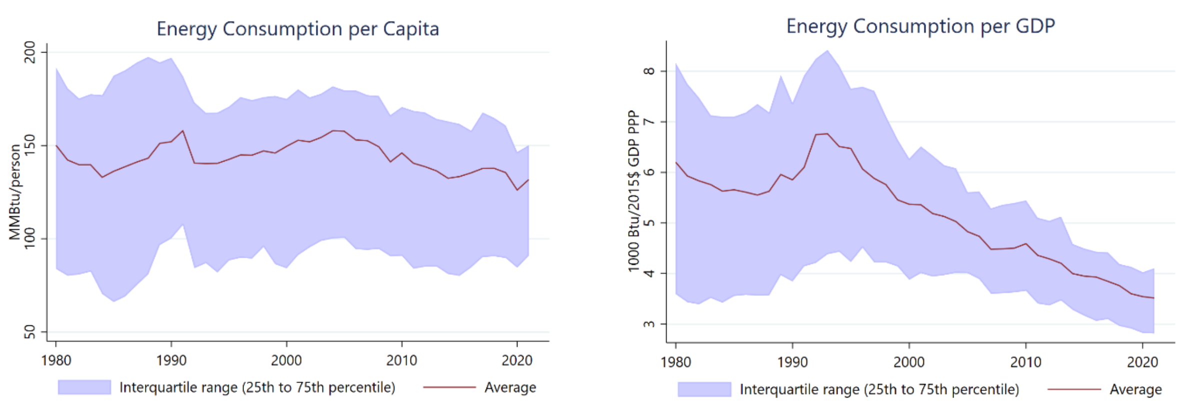
I. Introduction

The world is not decarbonizing fast enough. The increase in the global surface temperature has reached more than 1.1 degrees Celsius (°C) compared with the preindustrial average, before human-induced climate change began to take effect.[2] Projections show that accelerating climate change will raise the mean temperature above the 1.5°C threshold in the near term and by as much as 4°C over the next century absent a global green transition (Stern 2007; IPCC 2007, 2014, 2019; 2021). Shifting away from fossil fuels to renewables in energy production is a cornerstone of climate change mitigation. However, doing so at the pace required risks undermining the stability of the energy system and causing socioeconomic hardship. Greenhouse gas (GHG) emissions are fundamentally an outcome of (i) population, (ii) GDP per capita, (iii) carbon content of energy resources, and (iv) energy consumption per unit of GDP. Therefore, lowering GHG emissions requires the reduction of one or more of these four factors, which calls for policies focused on decarbonizing the energy mix (lower emissions per unit of energy) and enhancing energy efficiency (lower energy consumption per capita or unit of GDP).

Across Europe, total energy consumption has remained broadly unchanged at around 1,300 million tonnes of oil equivalent per year—or about 150 million British thermal unit (Btu) per capita—over the past four decades. However, the picture changes dramatically when we focus on the amount of energy used to produce a unit of GDP, which declined by 43.3 percent between 1980 and 2021 (Figure 1). This is owing to more energy-efficient production processes and greater energy efficiency of consumer goods and services as well as the changes in the energy mix and carbon leakage through international trade. Though an encouraging development, there is still significant cross-country variation in energy efficiency and even the best performing countries may not be realizing their full potential in energy efficiency. In our view, policymakers in Europe—and beyond—still have an opportunity both to achieve net zero emissions by 2050

Figure 1. Energy Efficiency in Europe



Source: EIA; authors' calculations.

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[2] The average global temperature in July 2023 was already about 1.5°C warmer than that of the pre-industrial period. However, it should be noted that a temporary increase of 1.5°C is different from the 2015 Paris Agreement target of limiting long-term global warming to 1.5°C by 2100.

and to strengthen economic prospects by increasing efficiency in the distribution and consumption of energy, along with changing the energy matrix from fossil fuels to renewables. As shown in Cevik (2022a; 2022b), a clean energy transition in Europe by changing the energy matrix and boosting energy efficiency could bring a significant reduction in GHG emissions, strengthen energy security, and make economies more resilient to climate change.

In this paper, we assess energy efficiency (or intensity) in a panel of 38 European countries over the period 1980–2021 by using the stochastic frontier analysis (SFA), which allows us to control for unobserved heterogeneity, disentangle inefficiency resulting from exogenous factors, and obtain time-varying estimations. The empirical results reveal statistically significant coefficients with intuitive signs and highlight two key findings. First, price signals, including through the introduction of a carbon tax and the removal of fossil fuel subsidies, are critical for energy efficiency, as consumers respond to changes in energy prices. Higher energy costs have a statistically and economically significant effect that incentivizes investments and behavioral changes to become more energy efficient. Second, a novel contribution of our analysis is the introduction of environmental policies and institutional quality, which provide more information on key policy factors influencing energy efficiency across Europe. We find that stronger environmental policies and institutions, as measured by the Environmental Policy Stringency (EPS) index and a composite index of bureaucratic quality, respectively, generate unambiguous improvements in energy efficiency by inducing investment in energy efficient equipment and buildings and nudging consumers for energy conservation.

With regards to conventional factors, we find that an increase in the level of real GDP per capita is associated with higher energy efficiency when it is measured by total energy consumption per unit of GDP, which better captures the differences in economic development and advancements in infrastructure and technology. Our results show that the structure of the economy exhibits a positive relationship with both measures of energy consumption in Europe. First, as widely accepted, industrial activity is associated with a higher level of energy consumption. Second, contrary to widespread expectations, we find that fast-growing services contribute to higher energy consumption, albeit at a lower rate compared to industry.

Economic globalization is found to enhance higher energy efficiency through technological progress and innovations and carbon leakage through international trade, which dampen down energy consumption by firms and households. Concerning demographic factors, we find opposing effects. While higher population density helps increase energy efficiency by inducing economies of scale, urbanization places greater strains on energy resources and lowers the level of efficiency. Another important sociodemographic factor in determining cross-country differences in energy efficiency is human capital. The higher the share of population with tertiary education, the lower the total energy consumption per capita or per unit of GDP. In our opinion, this reflects the energy efficient choices made by households with higher educational attainments as well as the catalytic effects of human capital accumulation on technology and productivity at the macro level.

All in all, the empirical analysis presented in this paper, robust to different specifications and estimation methodologies, indicate that the average level of energy efficiency in Europe remains below the frontier. Therefore, these results have important policy implications to reach—and move beyond—the current energy efficient frontier. First, promoting the accumulation of human capital through advanced education helps improve energy efficiency. Second, strengthening environmental policies and good governance is necessary to build a conducive investment environment and foster behavioral change across the society. Increasing energy efficiency in all sectors (including fast-growing services), along with expanding renewable energy generation, would not only help reduce Europe's dependency on imported sources of energy, but also help reduce GHG emissions in line with the net-zero target and deliver green growth.

The remainder of this paper is structured as follows. Section II provides an overview of the data used in the empirical analysis. Section III describes the econometric methodology and presents the empirical results. Finally, Section IV summarizes and provides concluding remarks.

II. Data Overview

The empirical analysis is based on an unbalanced panel of annual observations for 38 countries in Europe during the period 1980–2021.[3] The dependent variable is energy efficiency (or intensity) as measured by total energy consumption per unit of GDP and for robustness by total energy consumption per capita.[4] There is no single universally accepted measure of energy efficiency. While energy intensity measures the quantity of energy required per unit output at the aggregate level, energy efficiency measures the amount of energy used at the disaggregated level in individual activities. Accordingly, energy consumption per capita or per unit of GDP is the most commonly used aggregate measures of energy efficiency (Goh and Ang, 2020; IEA, 2021). As presented in Figure 1, a lower reading of energy consumption per unit of GDP (or per capita) implies a higher level of energy efficiency (or intensity). These series are obtained from the US Energy Information Agency (EIA).

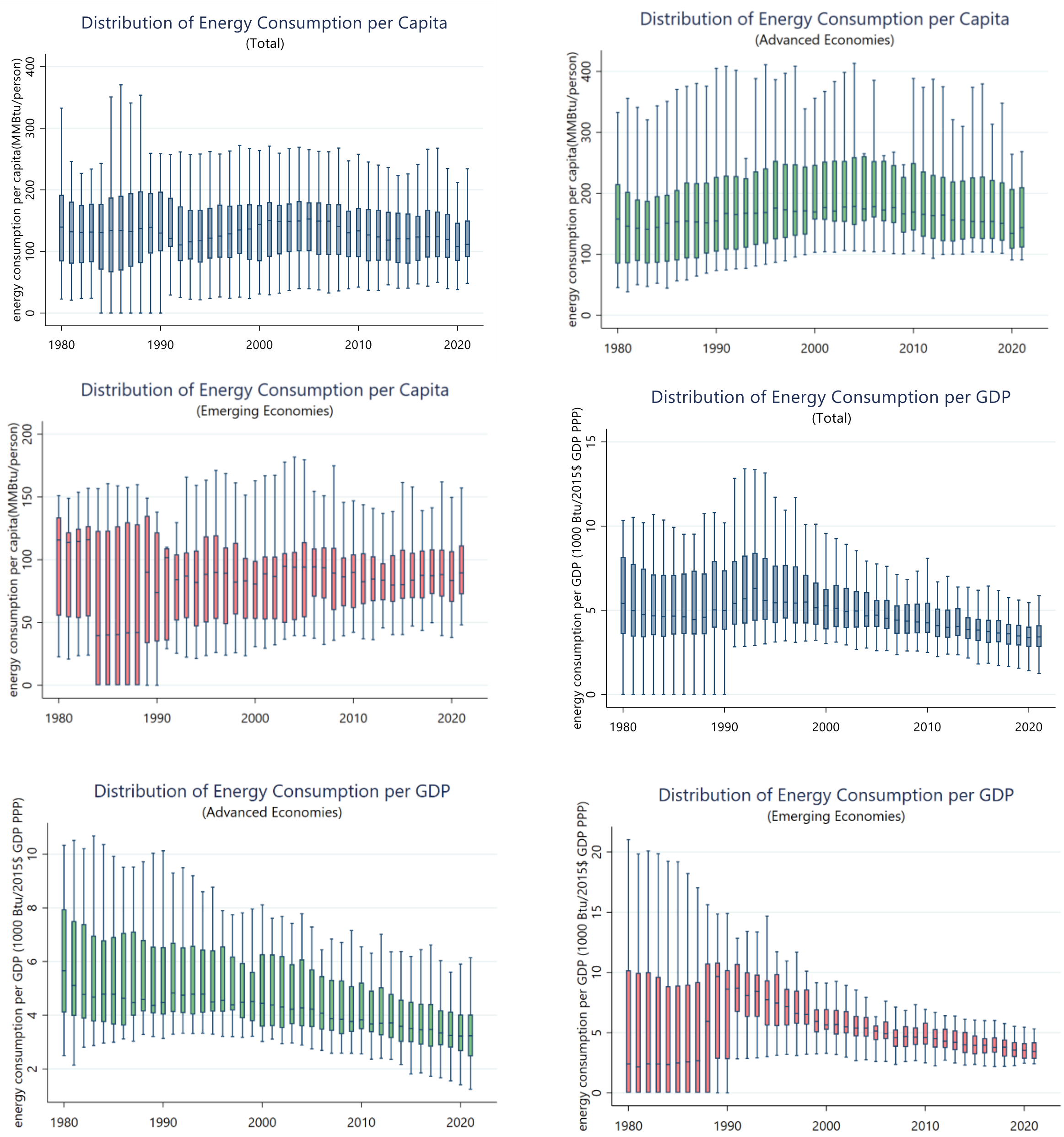
The selection of explanatory variables is based on the literature and data availability over a long span of time: (i) real GDP per capita; (ii) the share of industry and services in total value-added; (iii) trade openness as measured by the sum of exports and imports in GDP; (iv) the energy price index in real terms calculated by the EIA; (v) population and the share of urban population in total; (vi) educational attainments as measured by the share of population with tertiary education; (vii) the EPS index developed by the Organization for Economic Co-operation and

[3] The list of countries is presented in Appendix Table A2.

[4] In this paper, we use these terms interchangeably to capture energy efficiency (or intensity) as measured by total energy consumption per capita or per unit of GDP. Total energy consumption per capita is calculated by dividing total energy consumption in Btu by population for each country and year. Total energy consumption per unit of GDP is calculated by dividing total energy consumption in Btu for each country and year by GDP using purchasing power parities in billions of (2015) U.S. dollars. Total energy consumption includes the consumption of petroleum, dry natural gas, coal, net nuclear, hydroelectric, and non-hydroelectric renewable electricity, as well as net electricity imports (electricity imports – electricity exports) and net coke imports (coke imports – coke exports).

Development (OECD)[5], and (viii) a composite measure of institutional quality. These series are obtained from the World Bank, the OECD, the United Nations Conference on Trade and Development (UNCTAD) and the International Country Risk Guide (ICRG) databases. Descriptive statistics for the variables used in the empirical analysis are presented in Appendix Table A1. There is a significant degree of dispersion across countries in terms of energy efficiency and considerable heterogeneity in demographic, economic and institutional factors.

Figure 2. Distribution of Energy Efficiency Indicators



Source: EIA; authors' calculations.

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[5] The EPS is a multi-dimensional index based on 15 environmental policy instruments (Kruse *et al.*, 2022).

III. EMPIRICAL STRATEGY AND RESULTS

The objective of this paper is to provide an empirical analysis of energy efficiency based on a conceptual framework that captures a multitude of factors determining the level and evolution of energy efficiency (or intensity) across countries and over time. In line with the literature, this framework relates energy efficiency as measured by total energy consumption per unit of GDP (or per capita) to economic features, demographic characteristics, and institutional factors in each country. With regards to estimating technical efficiency in any given context, there are two families of methodologies—parametric and non-parametric. Each approach has advantages and disadvantages. Parametric methods require several assumptions on the errors' distribution and the functional form underpinning the model. At the same time, parametric methods assume a stochastic relationship between inputs and outputs allowing us to separate from the efficiency estimation the part that is real inefficiency and the part which is explained by measurement errors or other noise in the data. The flagship of the parametric methods is the SFA framework (Aigner, Lovell, and Schmidt, 1977; Jondrow *et al*., 1982; Greene, 2005; Kumbhakar, Wang, and Horncastle, 2015). Non-parametric methods, on the other hand, are based on mathematical programming and, therefore, do not require any assumption with regards to distribution and relative to the functional form of the transformation relation between outputs and inputs. However, nonparametric models such as the data envelopment analysis (DEA) are highly sensitive to the presence of outliers or noise in the data (Zhou, Ang, and Zhou, 2012).

In this paper, we estimate the economy-wide energy efficiency frontier by augmenting the SFA model used in Filipini and Hunt (2012) and Belotti *et al*. (2013), which takes the following log–log functional form in a cross-country panel setting:

$$\begin{aligned} EE_{it} = {} & \beta_1 GDP_{it} + \beta_2 IND_{it} + \beta_3 SER_{it} + \beta_4 OPN_{it} + \beta_5 EPI_{it} + \beta_6 POP_{it} + \beta_7 URB_{it} + \beta_8 EDU_{it} \\ & + \beta_9 EPS_{it} + \beta_{10} INS_{it} + \varepsilon_{it} \end{aligned}$$

where EE_{it} is energy efficiency (intensity) as measured by total energy consumption per unit of GDP and for robustness by total energy consumption per capita in country i at time t; GDP_{it} is real GDP per capita; IND_{it} and SER_{it} denote the share of industry and services in total value-added, respectively; OPN_{it} is a measure of trade openness; EPI_{it} is the energy price index in real terms; POP_{it} and URB_{it} denote population and the share of urban population, respectively; EDU_{it} is educational attainments as measured by the share of population with tertiary education; EPS_{it} denotes the EPS index created by the OECD; and INS_{it} is a measure of institutional quality. In the SFA framework, the error term ε_{it} is composed of two parts:

$$\varepsilon_{it} = \nu_{it} - \upsilon_{it,}$$

where $\nu_{i,t}$ is the random error term and υ_{it} is the inefficiency term. ν_{it} is assumed to have a normal distribution and independent of υ_{it}, as well as explanatory variables. On the other hand, the inefficiency term, υ_{it}, is a non-negative stochastic variable and assumed to follow an exponential distribution. Accordingly, υ_{it} represents the level of underlying energy (in)efficiency in country i and time t, which can be estimated with the SFA. In other words, the inefficiency term υ_{it} captures the gap between the maximum level of energy efficiency (frontier) and the actual level of energy efficiency owing to country-specific characteristics and policy preferences. With all variables in logarithmic form, the estimated coefficients can be interpreted as elasticities. Finally, we estimate the technical efficiency score using the SFA framework as suggested by Jondrow (1982) in the following form:

$$EF_{it} = \frac{EE_{it}^F}{EE_{it}} = \exp\left(-u_{it}\right)$$

where EE_{it} is energy efficiency as measured by total energy consumption per unit of GDP (or per capita), and EE_{it}^F is the predicted dependent variable—the frontier—in country i at time t.

For our baseline estimations, we apply the True Fixed Effect (TFE) model and for robustness the True Random Effect (TRE) model as proposed by Greene (2005) to account for country-specific characteristics and conditions.[6] These results are presented in Table 1 for energy efficiency as measured by energy consumption per unit of GDP (and in Appendix Table A3 for energy efficiency as measured by energy consumption per capita). We obtain statistically significant coefficients with intuitive signs, which should not be necessarily viewed as causal relationships. There are two key findings. First, price signals, including through the introduction of a carbon tax and the removal of fossil fuel subsidies, are also critical for energy efficiency, as consumers respond to changes in energy prices. We find that the real energy price index has a statistically and economically significant negative effect on total energy consumption per unit of GDP (or per capita). A one percent increase in energy prices in real terms is associated with a decline of 0.03 to 0.09 percent in total energy consumption per unit of GDP (and 0.09 to 0.10 percent in total energy consumption per capita). This means that higher energy costs incentivize investments and lifestyle changes—by firms and households—to become more energy efficient, confirming the important role of carbon pricing policies, such as national carbon taxes and the European Union's Emission Trading System (EU ETS), in climate change mitigation.

Second, a novel contribution of our analysis is the introduction of environmental policies and the quality of institutions, which provide more information on key policy factors influencing energy efficiency across Europe. Both the EPS and bureaucratic quality have statistically and economically significant effects on energy efficiency as measured by energy consumption per capita or per unit of GDP. First, we find that stronger environmental policies boost energy efficiency by inducing investment in energy efficient equipment and buildings and nudging consumers for greater energy conservation. A one percent increase in the EPS leads to a decline of 0.03 to 0.05 percent in total energy consumption per unit of GDP (or about 0.03 percent in total energy consumption per capita).[7] Second, we find that the strength of institutions as

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[6] As an additional robustness check, we estimate the time-invariant and time-varying models. These results, presented in Appendix Table A5, confirm our baseline findings.

[7] We also use the EPS covering only "market-based policies" aimed at climate change mitigation and obtain broadly similar results, which are presented in Appendix Table A4. The key finding in this exercise is that the impact of the EPS becomes more pronounced when we focus exclusively on climate change-related environmental policies.

Table 1. Determinants of Energy Efficiency: Baseline Results

	Energy Consumption per GDP	
	TFE	TRE
Real GDP per capita	-0.672***	-0.353***
	[0.034]	[0.007]
Share of industry in GDP	0.067***	0.097***
	[0.004]	[0.004]
Share of services in GDP	0.062***	0.099***
	[0.004]	[0.002]
Trade openness	-0.063**	-0.233***
	[0.028]	[0.015]
Energy price	-0.085***	-0.029*
	[0.029]	[0.018]
Population	-0.280***	-0.170***
	[0.085]	[0.009]
Urbanization	0.349***	0.250
	[0.104]	[0.000]
Educational attainments	-0.006***	-0.009***
	[0.001]	[0.001]
Environmental policy stringency	-0.030***	-0.048***
	[0.007]	[0.016]
Bureaucratic quality	-0.028**	0.009
	[0.013]	[0.000]
σ_u	-5.646***	-12.295***
	[0.142]	[0.000]
σ_v	-7.192***	-5.268***
	[0.200]	[0.018]
θ	-	0.342***
		[0.000]
Number of observations	517	517
Number of countries	38	38
Country FE	Yes	Yes
Time FE	Yes	Yes

Note: Robust standard errors clustered at the country level are reported in brackets. A constant is included in all specifications, but not shown in the table. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
Source: Authors' estimations.

measured by a composite index of bureaucratic quality is associated with higher energy efficiency by providing a more conducive investment environment and advancing behavioral changes. A one percent increase in bureaucratic quality leads to a decline of 0.03 percent in total energy consumption per unit of GDP (or 0.01 to 0.03 percent in energy consumption per capita).

With regards to conventional factors, we find that the elasticity of total energy consumption per unit of GDP with respect to real GDP per capita is negative within the range of -0.67 to -0.35 percent. That is, a higher level of economic development is associated with an increase in energy efficiency as measured by total energy consumption per unit of GDP, which is our preferred measure of energy efficiency as it better captures the state of the economy and productivity improvements.[8] The structure of the economy is found to exhibit a positive relationship with both measures of energy consumption in Europe. First, our results confirm that industrial activity is associated with energy-intensive production as widely accepted. Second, contrary to widespread expectations, we find that services contribute to higher energy consumption per unit of GDP (or per capita), albeit at a lower rate compared to industry. In our view, there are two important factors behind these results: (i) the decline in energy intensity of industrial production owing to technological advancements; and (ii) the increase in energy demand of fast-growing services (including transportation and communication) with lower levels of productivity.

Economic globalization—measured by the share of exports and imports in GDP—is found to enhance higher energy efficiency.[9] The coefficient on trade openness is not large in magnitude but statistically significant across all specifications. In our view, the effect of trade openness on energy efficiency captures technological progress and innovations and carbon leakage through international trade, which dampen energy consumption by firms and households. The extent of this effect depends on a country's absorptive capacity for technological advancements and the strength of its environmental policies.

Concerning demographic factors, we find opposing effects. First, population has a significant negative effect on total energy consumption per unit of GDP (or per capita). A one percent increase in population is associated with a decline of 0.17 to 0.28 percent in total energy consumption per unit of GDP (or 0.16 to 0.31 percent in total energy consumption per capita). Second, urbanization has a significant positive effect on total energy consumption per unit of GDP (or per capita). A one percent increase in urbanization is associated with an increase of 0.35 percent in total energy consumption per unit of GDP (or 0.37 to 0.76 percent in total energy consumption per capita). In other words, while higher population density helps increase energy efficiency by inducing the economies of scale, urbanization places greater strains on energy resources and lowers the level of efficiency.[10]

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[8] In the case of energy consumption per capita, the relationship becomes positive, with estimated coefficients in the range of 0.32 to 0.35 percent.

[9] We also use the KOF Globalization Index and obtain comparable results.

[10] The results remain unchanged if we exclude demographic factors, which provide valuable information on the economies of scale in production and distribution of energy in an efficient manner.

Another important sociodemographic factor in determining cross-country differences in energy efficiency is human capital as measured in this study by educational attainments. The coefficient on the share of population with tertiary education indicates a strong and statistically significant negative relationship between human capital and total energy consumption per unit of GDP (or per capita). A one percent increase in the share of population with advanced education leads to a decline of about 0.01 percent in total energy consumption per unit of GDP (or per capita). This may reflect the energy efficient choices made by households with higher educational attainments and greater environmental awareness as well as the catalytic effects of human capital accumulation on technology and productivity at the macro level.

IV. Conclusion

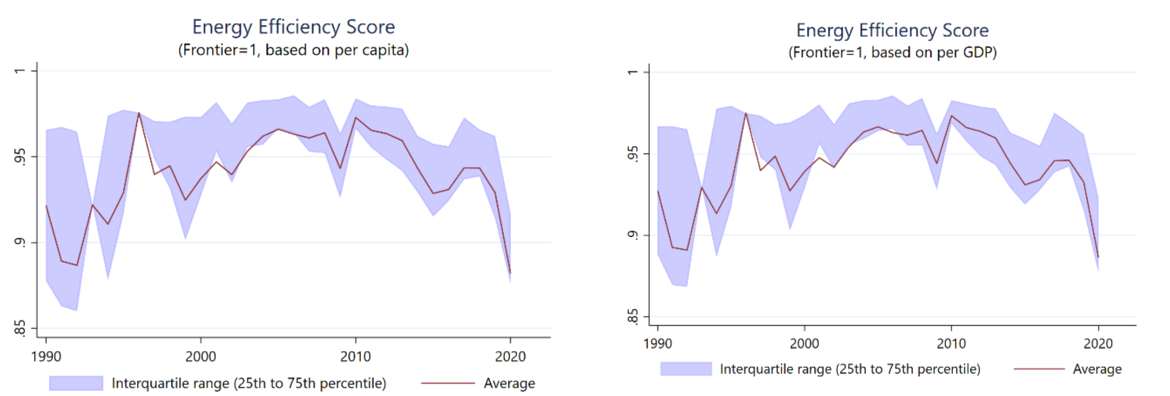
The average surface global temperature is already about 1.1°C warmer compared with the preindustrial average before human-induced climate change started to take effect. To limit global warming to 1.5°C requires halving GHG emissions by 2030 and bringing down to zero by 2050. Since more than two-thirds of GHG emissions come from fossil fuels that still generate about 80 percent of global energy needs, changing the energy matrix away from fossil fuels to renewables is certainly key for successful climate change mitigation. However, doing so fast enough to adequately reduce GHG emissions could undermine the stability of the energy system and cause socioeconomic hardship. Therefore, achieving net zero emission by 2050—necessary to avoid catastrophic climate events—and sustaining economic well-being requires a comprehensive set of policies and structural reforms aimed at decarbonizing the energy mix (lower GHG emissions per unit of energy) and boosting energy efficiency (lower energy consumption unit of GDP or per capita).

In this paper, we assess energy efficiency in a panel of 38 European countries over the period 1980–2021 by using the SFA approach, which allows us to control for unobserved heterogeneity and obtain time-varying estimations. The empirical results reveal statistically significant coefficients with intuitive signs and highlight two key findings. First, price signals, including through the introduction of a carbon tax and the removal of fossil fuel subsidies, are critical for energy efficiency, as consumers respond to changes in energy prices. Higher energy costs have a statistically and economically significant effect that incentivizes investments and behavioral changes to become more energy efficient. Second, a novel contribution of our analysis is the introduction of environmental policies and institutional quality, which provide more information on key policy factors influencing energy efficiency across Europe. We find that stronger environmental policies and institutions generate unambiguous improvements in energy efficiency by inducing investment in energy efficient equipment and buildings and nudging consumers for energy conservation.

With regards to conventional factors, we find that real GDP per capita is associated with higher energy efficiency when it is measured by total energy consumption per unit of GDP, which better captures the differences in economic development and advancements in infrastructure and technology. The structure of the economy, on the other hand, exhibits a positive relationship with both measures of energy consumption. Although fast-evolving technological advancements has helped reduce energy intensity in industrial production over time, services (including transportation and communication) contribute to lower level of energy efficiency. We find that economic globalization helps enhance higher energy efficiency through technological progress and innovations and carbon leakage through international trade, which dampen energy consumption by firms and households. Similarly, price signals, including through the introduction of a carbon tax and the removal of fossil fuel subsidies, are important in incentivizing investments to become more energy efficient.[11] While higher population density helps increase energy efficiency by inducing the economies of scale, urbanization places greater strains on energy resources and thereby lowers the level of efficiency. Another important sociodemographic factor is human capital (measured by educational attainments) that contributes to more energy efficient choices at the micro level as well as the catalytic effects on technology and productivity at the macro level.

On the whole, the empirical findings based on the SFA—robust to different specifications and estimation methodologies—indicate that the average level of energy efficiency in Europe remains about 10 percent below the frontier (Figure 3). This suggests that, on average, European countries are operating at about 90 percent of the efficiency frontier, with significant variation across counties.[12] Although raising the level of energy efficiency by 10 percent would not be enough to bring down GHG emissions towards the net-zero target by 2050, it would still make a significant contribution. Therefore, the econometric analysis presented in this paper have important policy implications to reach—and move beyond—the current energy efficiency

Figure 3. Energy Efficiency Scores in Europe



Source: Authors' estimations.

[11] The EU ETS is one of the most advanced carbon pricing schemes in the world, but it does not cover all economic activity. Furthermore, fossil fuel subsides in Europe account for 16 percent of explicit and 11 percent of explicit and implicit subsidies worldwide after a 300 percent increase during the recent surge in energy prices caused by Russia's invasion of Ukraine. Total subsides in Europe, however, amount to about 3 percent of GDP, compared to 10 percent in Asia and Pacific, 18 percent in the Middle East and North Africa, and 23 percent in the Commonwealth of Independent States (Black *et al.*, 2023).

[12] This finding is consistent with other studies in the literature, such as Kraiche, Kutlu, and Mao (2022) who found an average energy efficiency of about 92 percent in Europe during the period 1990-2015.

frontier. First, raising economic growth, strengthening trade integration, and promoting the accumulation of human capital through advanced education contribute to greater energy efficiency gains. Second, strengthening environmental policies and good governance is necessary to build a conducive investment environment and foster behavioral change across the society. Third, as shown by Cevik and Jalles (2023), structural reforms in the energy sector should be designed not just for market efficiency but also for environmentally sustainable growth with higher productivity and lower GHG emissions. Increasing energy efficiency in all sectors (including fast-growing services), along with expanding renewable energy generation, would not only help reduce Europe’s dependency on imported sources of energy, but also help reduce GHG emissions in line with the net-zero target and deliver green growth.

Appendix Table A1. Descriptive Statistics

	Mean/Prop.	SD	Min.	Max.	N
Energy consumption per capita	143.26	83.20	.00	441.65	1353.00
Energy consumption per GDP	5.02	2.45	.00	21.02	1314.00
Real GDP per capita	26552.90	21507.12	698.22	112401.95	1378.00
Educational attainment	33.12	12.18	5.60	63.12	647.00
Share of industry	29.27	7.07	11.40	55.98	1341.00
Share of services	64.98	10.84	12.97	88.06	1341.00
Energy price index	88.21	20.12	18.25	240.72	1040.00
Population	15751667.51	21754597.99	228138.00	84775404.00	1554.00
Urban population	68.80	14.14	33.76	98.12	1512.00
Environmental policy stringency index	2.14	1.13	.00	4.89	775.00
Bureaucratic quality index	3.20	.89	.00	4.00	1094.00

Appendix Table A2. List of Countries in the Sample

Albania	Denmark	Ireland	Netherlands	Slovenia
Austria	Estonia	Italy	North Macedonia	Spain
Belgium	Finland	Kosovo	Norway	Sweden
Bosnia and Herzegovina	France	Latvia	Poland	Switzerland
Bulgaria	Germany	Lithuania	Portugal	Turkey
Croatia	Greece	Luxembourg	Romania	United Kingdom
Cyprus	Hungary	Malta	Serbia	
Czechia	Iceland	Montenegro	Slovakia	

Appendix Table A3. Determinants of Energy Efficiency: Alternate Measure

	Energy Consumption per Capita	
	TFE	TRE
Real GDP per capita	0.351***	0.315***
	[0.062]	[0.011]
Share of industry in GDP	0.061***	0.060***
	[0.004]	[0.003]
Share of services in GDP	0.056***	0.051***
	[0.004]	[0.003]
Trade openness	-0.068**	-0.034***
	[0.028]	[0.004]
Energy price	-0.086***	-0.095***
	[0.029]	[0.026]
Population	-0.311***	-0.156***
	[0.087]	[0.004]
Urbanization	0.367***	0.758***
	[0.104]	[0.027]
Educational attainments	-0.006***	-0.006***
	[0.001]	[0.000]
Environmental policy stringency	-0.028***	-0.032***
	[0.007]	[0.006]
Bureaucratic quality	-0.027**	-0.006
	[0.013]	[0.008]
σ_u	-5.585***	-5.449***
	[0.139]	[0.131]
σ_v	-7.237***	-7.248***
	[0.204]	[0.202]
θ	-	0.297***
		[0.004]
Number of observations	517	517
Number of countries	38	38
Country FE	Yes	Yes
Time FE	Yes	Yes

Note: Robust standard errors clustered at the country level are reported in brackets. A constant is included in all specifications, but not shown in the table. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
Source: Authors' estimations.

Appendix Table A4. Determinants of Energy Efficiency: Alternative EPS

	Energy Consumption per Capita		Energy Consumption per GDP	
	TFE	TRE	TFE	TRE
Real GDP per capita	0.356***	0.221***	-0.660***	-0.365***
	[0.037]	[0.009]	[0.035]	[0.011]
Share of industry in GDP	0.054***	0.069***	0.059***	0.043***
	[0.004]	[0.002]	[0.004]	[0.004]
Share of services in GDP	0.048***	0.057***	0.053***	0.036***
	[0.004]	[0.002]	[0.004]	[0.004]
Trade openness	-0.053*	0.030***	-0.052*	-0.118***
	[0.029]	[0.011]	[0.029]	[0.031]
Energy price	-0.129***	-0.150***	-0.129***	-0.118**
	[0.027]	[0.021]	[0.027]	[0.033]
Population	-0.093	-0.088***	-0.068	-0.124***
	[0.092]	[0.004]	[0.089]	[0.008]
Urbanization	0.329***	0.792***	0.298***	0.745***
	[0.108]	[0.021]	[0.107]	[0.051]
Educational attainments	-0.007***	-0.007***	-0.007***	-0.009***
	[0.001]	[0.000]	[0.001]	[0.001]
Environmental policy stringency	-0.038***	-0.044***	-0.040***	-0.041***
	[0.006]	[0.004]	[0.006]	[0.005]
Bureaucratic quality	-0.019	0.001	-0.020	0.026***
	[0.012]	[0.008]	[0.012]	[0.011]
σ_u	-5.739***	-5.429***	-5.849***	-0.011***
	[0.157]	[0.130]	[0.159]	[0.001]
σ_v	-7.175***	-7.346***	-7.066***	-5.624***
	[0.220]	[0.211]	[0.196]	[0.157]
θ	-	0.340***	-	-6.743***
		[0.004]		[0.184]
Number of observations	517	517	517	517
Number of countries	38	38	38	38
Country FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Note: Robust standard errors clustered at the country level are reported in brackets. A constant is included in all specifications, but not shown in the table. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
Source: Authors' estimations.

Appendix Table A5. Determinants of Energy Efficiency: Robustness Checks

	Energy Consumption per Capita		**Energy Consumption per GDP**	
	Time-invariant	Time-varying decay	Time-invariant	Time-varying decay
Real GDP per capita	0.479***	0.358***	-0.505***	-0.478***
	[0.033]	[0.025]	[0.038]	[0.024]
Share of industry in GDP	0.055***	0.062***	0.057***	0.060***
	[0.005]	[0.004]	[0.005]	[0.004]
Share of services in GDP	0.055***	0.066***	0.058***	0.068***
	[0.005]	[0.004]	[0.005]	[0.004]
Trade openness	-0.074**	0.184***	-0.073**	0.188***
	[0.033]	[0.031]	[0.034]	[0.032]
Energy price	-0.082***	-0.211***	-0.091**	-0.238***
	[0.037]	[0.030]	[0.036]	[0.031]
Population	-0.171***	-0.167***	-0.157***	-0.226***
	[0.039]	[0.023]	[0.046]	[0.027]
Urbanization	0.403***	0.438***	0.445***	0.615***
	[0.114]	[0.104]	[0.118]	[0.108]
Educational attainments	-0.009***	-0.001	-0.009***	-0.001
	[0.001]	[0.001]	[0.001]	[0.001]
Environmental policy stringency	-0.034***	0.003	-0.036***	-0.001
	[0.009]	[0.008]	[0.009]	[0.008]
Bureaucratic quality	-0.040***	-0.014	-0.036**	-0.010
	[0.015]	[0.013]	[0.015]	[0.013]
η	-	-0.013***	-	-0.011***
		[0.001]		[0.001]
σ_u^2	0.370	0.366	0.317	0.408
σ_v^2	0.065	0.053	0.064	0.054
Number of observations	517	517	517	517
Number of countries	38	38	38	38

Note: Robust standard errors clustered at the country level are reported in brackets. A constant is included in all specifications, but not shown in the table. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
Source: Authors' estimations.

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