Do Fossil Fuel Subsidies Delay the Low-Carbon Transition? Evidence from the OECD

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***Abstract*—Since the 1970s, fossil fuel subsidies (FFS) have been widely adopted to stabilize economies and protect consumers from energy price volatility. However, these subsidies have contributed to increased greenhouse emissions, resource depletion, and air pollution. This study investigates the relationship between fossil fuel subsidies and greenhouse emissions in OECD countries from 2010 to 2022 using a fixed-effects panel model. Results indicate that a 1 percentage point increase in fossil fuel subsidies (as a share of GDP) raise emissions per capita by 0.69 tons. Among the various subsidy types, those directed at oil products have the most significant impact on emissions. These outcomes suggest that FFS hinder climate goals, emphasizing the need for targeted policy reforms.**

***Index Terms* - climate change, fixed-effects panel model, fossil fuel subsidies, greenhouse gas emissions, OECD countries**

I. INTRODUCTION

Fossil fuel subsidies (FFS) – i.e., government intervention that lowers the cost of fossil fuel production or consumption [1] – have long been employed by governments to shield consumers from volatile energy prices and support domestic energy industries. However, these subsidies may contradict global climate objectives by encouraging fossil fuel consumption and delaying the shift toward cleaner energy sources. Despite their significant impact on global carbon emissions, FFS are often overlooked in international climate agreements [2].

Studies have shown that these subsidies not only raise the cost of climate change mitigation but also contribute to increased environmental degradation. Kovacevic [3], for instance, found that FFS can increase the cost of climate mitigation by up to 25% of a country's GDP, while Solarin [4] demonstrated that a 10% rise in FFS results in a 0.3-1.5% increase in ecological footprint.

The persistence of FFS is largely driven by political and institutional factors. Mahdavi et al. [5] argue that fuel subsidy levels are influenced more by political considerations than by environmental commitments, while Droste et al. [6] emphasize the influence of fossil fuel lobbies in sustaining these subsidies and obstructing climate policies in key OECD economies. Similarly, Curran [7] documents how the coal industry has shaped Australian policymaking, illustrating how entrenched interests hinder the shift to clean energy. Addressing these barriers requires coordinated efforts at both national and international levels to depoliticize subsidy reforms and prioritize long-term sustainability.

The economic and social dimensions of FFS phase-out remain a critical area of debate. Monasterolo and Raberto [8] argue that subsidy removal fosters green economic growth while reducing emissions. However, the distributional consequences of subsidy reform are complex, particularly in regions heavily reliant on fossil fuel industries. Kuehl et al. [9] concluded that eliminating these subsidies could lead to positive impacts, namely a 6.09% reduction in GHG emissions across G20 nations by 2030. Similarly, Adekunle and Oseni [10] find that subsidy removal in Nigeria correlates with lower carbon emissions, though short-term socio-economic challenges persist. Antimiani et al. [11] further suggest that an integrated policy approach, combining FFS removal with green technology investments, is essential for a successful transition.

Despite mounting evidence of FFS environmental and economic drawbacks, they persist in OECD countries, fueled by political inertia and economic considerations. The energy policies of OECD nations have historically prioritized economic growth and energy security, often at the expense of environmental sustainability. Fossil fuel subsidies, in the form of direct transfers and tax expenditures, amounted to USD 427.9 billion in 2022 [12], reflecting the reliance on such measures. Recent geopolitical events, including the Russian-Ukrainian war, have prompted many governments to increase subsidies to counteract rising energy costs. While these subsidies aim to mitigate energy poverty and protect key industries, they inadvertently perpetuate the dominance of fossil fuels and impede the transition to renewable energy, raising critical questions about the long-term implications of FFS on emissions and energy transitions.

As OECD countries play a significant role in global economic and political processes, these countries are expected to lead climate policy due to their high energy consumption and historical emissions responsibility.

Thus, the current study fills in a significant gap in the literature by addressing FFS provided by the OECD and analyzing the extent to which these subsidies contribute to greenhouse gas (GHG) emissions and hinder decarbonization efforts. The findings contribute to the ongoing policy debate on subsidy reform and its role in facilitating the low-carbon transition.

II. METHODOLOGY

To analyze the impact of FFS on GHG emissions across OECD countries, this study applies an econometric analysis based on a fixed-effects panel data model, complemented by pooled ordinary least squares (POLS) and random effects models as robustness checks. The model assesses how variations in FFS levels, disaggregated by fuel type influence GHG per capita emissions

A. Empiral Model

The empirical analysis employs a fixed-effects panel regression model, expressed as follows:

$$Y_{i,t} = \alpha + X_i' \cdot \beta + u_{i,t} \quad (1)$$

In this formula, for *i*= 1,..., N and *t*= 1,..., T, where $Y_{i,t}$ is the dependent variable (GHG emissions per capita), X_i' is the vector of independent variables (e.g., FFS and FFS per fuel type), β is the coefficient vector of independent variables, and $u_{i,t}$ is the composite error, in the following form:

$$u_{i,t} = \mu_i + v_{i,t} \quad (2)$$

where μ_i is the unobservable individual-specific effect, and $v_{i,t}$ is the remainder disturbance. μ_i is time-invariant, and it takes into account any individual-specific impact that is left out of the regression. $v_{i,t}$ differs from individual to individual and time and can be considered the usual disturbance in the regression. The fixed effects μ_i are not directly predictable. Each μ_i is a discrete constant associated with a particular group or cross-section. The remaining disturbances $v_{i,t}$ are stochastic, independent, and uniformly distributed (iid). The explanatory variables are independent of $v_{i,t}$. The fixed effects model is preferred when all independent variables are conditionally related to individual effects.

Equation (1) is estimated using a fixed effects (FE) model. We first run panel unit root tests to detect if all groups (i.e. the corresponding variable for each country in this case) contain unit roots. We selected the Augmented Dickey-Fuller test with constant and trend for this purpose and confirm that none of the variables have unit roots. Besides, after running tests for and detecting autocorrelation and heteroskedasticity, we use the spatial correlation consistent (SCC) estimator developed by Driscoll and Kraay [13], which addresses cross-sectional dependence of the disturbances as well as heteroskedasticity and autocorrelation.

Serial correlation is handled in the manner of Newey–West and, unlike the Arellano estimator, consistency is not limited to the "small T" case (although in our sample, many units are observed in relatively few periods) [14]. These standard errors are robust to serial correlation, heteroskedasticity, and cross-sectional dependence.

Additionally, we apply robustness checks using alternative model specification. First, pooled ordinary least squares (POLS) regressions are run, which are the simplest estimators for panel data and serve as a baseline for comparison with more complex estimators such as FE and random effects [14]. Second, following Baltagi and Wu [15], panel generalized least squares (GLS) regressions are run estimating Driscoll-Kraay standard errors again as the robust option. The GLS method is chosen for estimating a random effects model which tackles autocorrelation in the error terms caused by the individual-specific effects.

B. Variables and Data Sources

In this study, we used a series of variables such as:

- **Fossil Fuel Subsidies (FFS)**, calculated as percentage of GDP and categorized by fuel type (electricity: **FFS_EL**; natural gas: **FFS_GAS**; petroleum products: FFS_OIL; coal: **FFS_COAL**) [12]
- **Greenhouse gas emissions per capita (GHGPC),** measured in tonnes CO_2eq/capita/year [16]

Several control variables are included in the equations to consider the economic and policy characteristics of the countries in different years. Among these control variables responsible for contributing to an increase or decrease of GHGPC are:

- **GDP per Capita (GDPPC)**, measured in constant 2021 international dollars [16]
- **Industrial Value Added (IND)**, expressed as percentage of GDP [16]
- **Climate Taxation (CLIMTAX)**, as percentage of GDP [17]
- **Renewable Electricity Output (REO)**, representing the percentage of total electricity production [18]

TABLE 1 provides a summary of the descriptive statistics of the variables used in our empirical analysis for the 2010-2022 sample period, covering all the OECD countries.

TABLE 1. DESCRIPTIVE STATISTICS OF THE VARIABLES

Variable	Mean	Median	S.D.	Min	Max
GHGPC	10.5	8.97	5.06	2.99	27.2
FFS	0.0586	0.0214	0.112	0.000	1.39
FFS_EL	0.0101	0.000	0.0481	0.000	0.901
FFS_GAS	0.0198	0.00181	0.0482	0.000	0.461
FFS_OIL	0.0175	0.000320	0.0535	0.000	0.469
FFS_COAL	0.0112	3.45e-005	0.0219	0.000	0.183
CLIMTAX	1.90	1.89	0.788	-1.14	4.15
GDPPC	49,464	46,137	22,059	14,281	137,947
IND	24.2	24.2	5.82	10.4	49.2
REO	38.3	32.1	26.4	0.290	100

III. RESULTS AND DISCUSSION

This section presents and discusses the results of the estimation model to test the observed relationship between FFS and GHG emission

TABLE *2* presents the fixed effects estimation results in four separate models that include different categories of FFS as explanatory variables. Model 1 integrates the effects of total FFS (direct transfers as a % of GDP) on GHGPC, whereas Models 2, integrate the effects of FFS by fuel source.

TABLE 2. FIXED EFFECTS ESTIMATION RESULTS PER MODEL AND VARIABLE - COEFFICIENT AND [ROBUST STANDARD ERROR]

	Model 1 GHGPC	***Model 2 GHGPC***
FFS	0.69** [0.28]	
FFS_EL		−0.68 [0.46]
FFS_GAS		0.16 [0.86]
FFS_OIL		3.44*** [0.53]
FFS_COAL		-1.16 [1.47]
CLIMTAX	−0.04 [0.12]	-0.06 [0.13]
GDPPC	4.76*** [1.19]	4.88*** [1.26]
IND	-0.01 [0.02]	-0.02 [0.02]
REO	-0.07*** [0.01]	-0.07*** [0.01]
Constant	−36.77*** [12.71]	−37.82*** [13.29]
time dummies	Yes	Yes
Observations	475	475
LSDV R-squared	0.98	0.98

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

FFS reduce the cost of fossil fuel consumption, leading to market distortions that encourage excessive fossil fuel use and increase GHG emissions. This is reveled in Model 1, which indicates that a 1 percentage point increase in total FFS leads to a 0.69-tonne rise in per capita GHG emissions. In the same analysis, GDP per capita makes a significant contribution to emissions per capita; i.e. being a wealthier economic country in average per capita terms implies an increase in the GHG each person emits on average. To be more precise, a 1 percentage increase in GDPPC leads to 4.76 tonnes of increase in emissions per capita, higher than FFS. On the other hand, renewable energy output (REO), contributes to the low-carbon transition significantly by decreasing emissions by 0.07 tonnes as REO increases by 1 percentage point. The insignificance of climate taxation (CLIMATAX) suggests that current policies may be insufficient in offsetting the effects of FFS.

Model 2 further disaggregates FFS by fuel type and finds that oil-related subsidies have the most significant impact on emissions, with a 1 percentage point increase leading to 3.44 additional tonnes of GHG emissions per capita. This aligns with the fact that oil is primarily used in transportation, one of the most carbon-intensive sectors and a major contributor to emissions in OECD economies.

By contrast, subsidies to coal and electricity do not exhibit a statistically significant impact on emissions. The non-significance of coal subsidies may be explained by the declining role of coal in electricity generation in many OECD countries, where coal phase-out policies and carbon pricing mechanisms have constrained its use. The insignificance of electricity-related FFS suggests that subsidies to fossil fuel-based electricity generation may be counterbalanced by increasing shares of renewables in power systems. In fact, the share of renewable electricity has grown on average more than 2.3 times between 2010 and 2022 on OECD economies.

Subsidies to natural gas show a positive but statistically insignificant effect on emissions. This could reflect the dual role of natural gas as both a transitional fuel (with lower emissions than coal and oil) and a potential barrier to deep decarbonization if over-subsidized. While natural gas is less carbon-intensive than coal, continued subsidies for gas infrastructure may lock in fossil fuel dependence and slow the adoption of zero-carbon alternatives. In contrast, subsidies for gas, coal, and electricity appear to have a less pronounced effect, potentially due to regulatory frameworks (e.g., EU Emissions Trading Scheme) and the significant integration of renewable energy in power sector (the main consumer of these products).

The significant relevance of oil-related subsidies, particularly after 2016 aligns with the empirical findings from Model 2, where petroleum products subsidies show the most significant effect on emissions (Figure 1). Overall, Figure 1 highlights how FFS have escalated in response to recent economic and geopolitical shocks, namely Ukraine War, underscoring the challenge of aligning energy subsidies with climate goals.

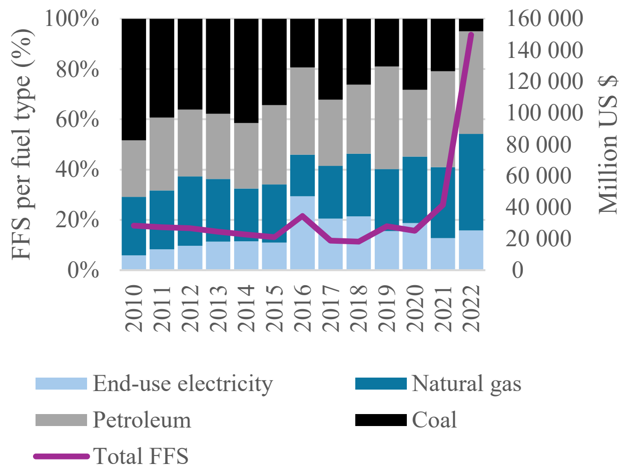

FIGURE 1. Trends in Fossil Fuel Subsidies by Fuel Type (2010–2022): Relative Shares (Left Axis) and Total Subsidies in Absolute Terms (Right Axis)

TABLE 3. SUMMARY OF THE ROBUSTNESS TEST

Test	Null Hypothesis (H_0)	Test Statistic	p-value	Result	Implication
Wooldridge Test (Autocorrelation)	No first-order autocorrelation	F(1, 36) = 357.90	2.73E-20	Reject H_0 (Autocorrelation present)	Serial correlation detected; requires robust standard errors.
Wald Test (Heteroskedasticity)	Residuals have homoscedastic variance	$\chi^2(37)$ = 12498.3	0	Reject H_0 (Heteroskedasticity present)	Unequal variance across observations; requires robust standard errors.
Augmented Dickey-Fuller (ADF) Test	Panel data contains unit roots (non-stationary)	Varies by variable	Mostly p < 0.05	Mixed results; no unit root in key variables	No strong evidence of non-stationarity.
Driscoll-Kraay Standard Errors	No cross-sectional dependence, autocorrelation, or heteroskedasticity	Applied as correction	–	Addressed issues	Ensures robust standard errors, making coefficients reliable.

To ensure the reliability of our estimates, we first conducted several robustness tests. The Wooldridge test for autocorrelation indicated the presence of serial correlation ($F(1, 36) = 357.90$, $p < 0.0001$), while the Wald test for heteroskedasticity confirmed non-constant variance across observations ($\chi^2(37) = 12498.3$, $p < 0.0001$) (TABLE 3). Additionally, we performed panel unit root tests (Augmented Dickey-Fuller) to check for non-stationarity in the data, finding no strong evidence of unit roots in the key variables. Further we applied Driscoll-Kraay standard errors, which adjust for heteroskedasticity, autocorrelation, and cross-sectional dependence. As a result, we can argue that the statistical significance and validity of our estimated coefficients remain robust.

CONCLUSIONS

FFS have historically been used to shield consumers from volatile energy prices and support domestic energy industries. However, these subsidies contradict global climate objectives by promoting fossil fuel consumption and delaying the transition to cleaner energy sources.

The study confirms that fossil fuel subsidies, obstruct decarbonization efforts in OECD countries, raising per capita GHG emissions by over 3 tonnes per person per year for every percentage point increase in FFS. Policymakers should thus prioritize the elimination of oil-related subsidies while ensuring that economic and social considerations are addressed through well-structured policy measures.

Future research will explore the differentiated effects of FFS across sectors and beneficiary types, as well as the broader macroeconomic and social implications of subsidy removal. A deeper understanding of these dynamics will be crucial for designing policies that ensure a just and equitable transition to a sustainable, low-carbon economy.

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