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FOSSIL FUEL SUBSIDIES AND GHG EMISSIONS: FIRM-LEVEL EMPIRICAL EVIDENCE FROM DEVELOPING ASIA

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Abstract

Given the commitment of G7 and G20 countries to the gradual elimination of fossil fuel subsidies and their advocacy for other nations to follow suit, this study examines the effects of such subsidies on firms' GHG emissions. Utilizing a dataset comprising 3,359 firms across seven countries in developing Asia, namely, the People's Republic of China (PRC), India, Indonesia, Malaysia, Pakistan, Thailand, and Viet Nam, we demonstrate that a firm's GHG emissions, encompassing both absolute GHG emissions and GHG emission intensity, exhibit an upward trajectory concurrent with an escalation in fossil fuel subsidies. This observed correlation extends to both subsidies per unit of energy and subsidies relative to GDP, with subsidies allocated to crude oil exerting a notably more pronounced impact than those designated for gas and electricity. Furthermore, our analysis demonstrates heterogeneity in outcomes across firms situated in diverse regions and sectors. Particularly, the impact of fossil fuel subsidies on firms' emissions is greater in sectors characterized by low energy consumption, compared to those with high energy consumption. This discrepancy is probably attributed to a lack of cost-competitive low-carbon substitutes and non-energy emissions. While fossil fuel subsidies have a positive impact on firms' GHG emissions in Southeast Asia, no significant effect is documented for the PRC or South Asia.

Keywords: fossil fuel subsidy, energy subsidy, GHG emissions, hard-to-abate sectors

JEL Classification: Q30, Q38, Q42, Q48, Q53, Q58

Contents

1. INTRODUCTION

The paramount concern associated with fossil fuel subsidies revolves around their substantial contribution to climate change and environmental degradation (Arzaghi and Squalli 2023; Solarin 2020). These subsidies reduce the cost of fossil fuels, incentivizing greater consumption, which then results in elevated greenhouse gas (GHG) emissions. This undermines global efforts to combat climate change and make the transition to cleaner, renewable energy sources.[1] Recent studies have shown that fossil fuel consumption stands as the crucial driver behind the escalating levels of carbon dioxide (CO_2) emissions (Le Quéré et al. 2019; Liang, Zhang, and Qiang 2022). Elevated levels of fossil fuel subsidies exhibit a positive correlation with heightened GHG emissions (Arzaghi and Squalli 2023; Jewel et al. 2018; Ellis 2010). Countries with substantial fossil fuel subsidies emit 11.4% more GHG emissions than countries with high fossil fuel taxes (Arzaghi and Squalli 2023). Fossil fuel subsidies increase GHG emissions in two ways: they serve as an incentive for the consumption of fossil fuel and as a barrier for low-carbon energy solutions. Global CO_2 emissions surged to 32 billion metric tons in 2020, with a staggering 90% of these emissions being attributable to the utilization of fossil energy sources (BP 2021). Moreover, fossil fuel subsidies are often criticized for being one of the major barriers to the adoption of low-carbon solutions such as renewable energy, energy efficiency, etc. Low energy costs resulting from subsidies may weaken incentives to promote renewable energy and energy efficiency (Sovacool 2017; Li and Solaymani 2021), and subsequently increase consumption and carbon emissions in all economic sectors.

Apart from their contribution to GHG emissions, fossil fuel subsidies have been criticized for their inefficiency (Anbumozhi et al. 2023; De Bruin and Yakut 2023). Subsidized energy is provided to give households and firms the benefit of affordable energy, with the aim of supporting the poor and increasing the competitiveness of local goods (Lin and Li 2012). However, higher income groups usually benefit more than lower income groups because members of these groups have bigger houses and cars, while subsidies are a burden on public expenditure that has reached 4% of GDP[2] and exceeds public spending on education or health in some Asian countries (ADB 2016). For the above reasons, it is recommended that governments replace inefficient fossil fuel subsidies with targeted support to address energy poverty issues.

Despite the reasons given above for the removal of fossil fuel subsidies, in 2022, globally, fossil fuel subsidies nearly doubled compared to the figures for 2021 (Figure 1), mainly due to subsidies on natural gas (an increase of 2.5 times), electricity (a doubling), and crude oil (an 83% increase). Fossil fuel subsidies increased because of the sharp energy price increase caused by the Russian invasion of Ukraine.

However, the impact of subsidy reductions on GHG emissions (or fossil fuel consumption) is not clear. While some studies show environmental benefits from subsidy reductions (Jewell et al. 2018; Ellis 2010; Arzaghi and Squalli 2023; Chepeliev and Mensbrugghe 2020), others show no effect or even damaging effects of subsidy reductions on the environment (Greve and Lay 2023). Although energy price increase via subsidy reductions should incentivize reductions in energy consumption and

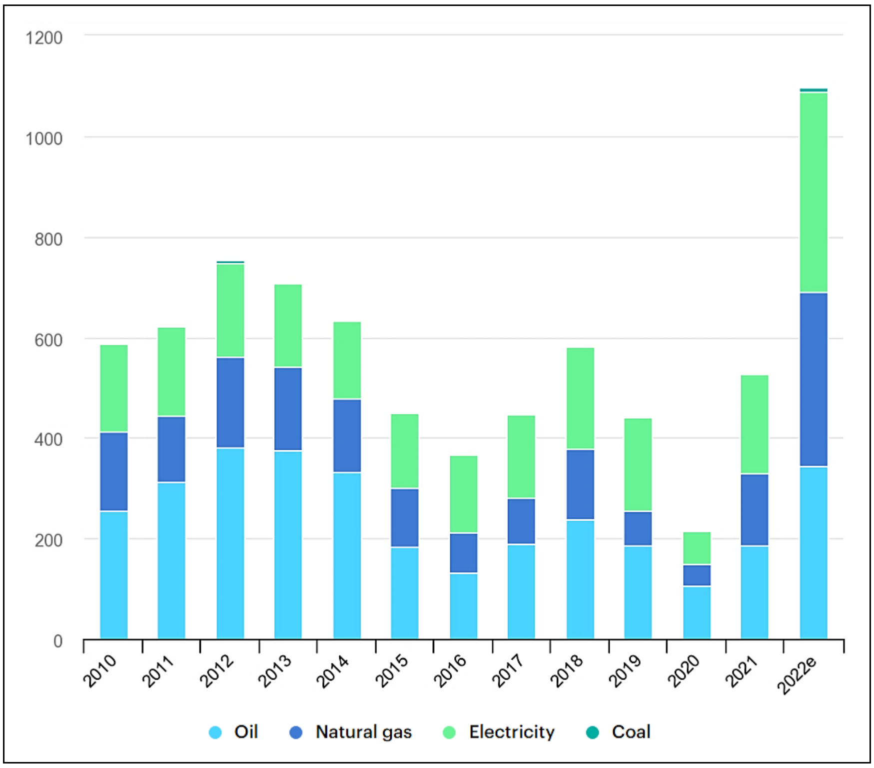
[1] It is worth noting that renewable energy technologies, recognized as a pivotal means to address climate change and global warming, have garnered escalating attention due to their advantageous attributes, including reduced pollution and environmentally sustainable production practices (Azhgaliyeva and Le 2022; Azhgaliyeva and Le 2023).

[2] Fossil fuel subsidies in India, Indonesia, and Thailand were at 2.7%, 4.1%, and 1.9% of GDP, respectively, in 2012 (ADB 2016).

improvements in energy efficiency, the impact could be limited due to several reasons. For example, due to a switch to relatively cheaper but more polluting fuels (e.g., switch from electricity to coal or diesel); non-energy emissions; and due to the lack of low-emission substitutes, especially in the hard-to-abate sectors (e.g., steel and cement) in which renewable electricity cannot replace fossil fuels because of the need for high temperatures which are hard to achieve using renewable energy. Green hydrogen could be a substitute for fossil fuel in hard-to-abate sectors, but it is still a less mature technology (compared to renewable energy), with a current cost well above the cost of fossil fuel.

For the above reasons, it is important to study the impact of fossil fuel subsidies on GHG emissions, and to provide policy recommendations for the efficient implementation of the reduction or phasing out of fossil fuel subsidies.[3] This paper aims to contribute to the existing literature by providing empirical evidence on the ex-post environmental impact of fossil fuel subsidies at firm level, since this evidence is very scant for developing Asia. The remainder of this paper is structured as follows. Section 2 provides the data and variables. Section 3 explains the methodology. Section 4 provides the results. Section 5 provides robustness checks. Section 6 concludes and provides policy recommendations.

Figure 1: Fossil Fuel Consumption Subsidies by Fuel, 2010–2022



Source: IEA 2023; Fossil Fuels Consumption Subsidies 2022, https://www.iea.org/reports/fossil-fuels-consumption-subsidies-2022, License: CC BY 4.0.

[3] The G7 and G20 countries are committed to phasing out fossil fuel subsidies. The G7 countries have specified a target year of 2025.

2. RESEARCH DATA

To investigate the effects of fossil fuel subsidies on firms' GHG emissions, we construct unique panel datasets of firms from emerging countries in Asia and the Pacific that provided fossil fuel subsidies between 2010 and 2021. Emissions data are collected from S&P Capital IQ Pro. The information on fossil fuel subsidies is obtained from the International Energy Agency (IEA). Ultimately, we have a sample of 3,359 firms from seven countries from developing Asia: the People's Republic of China (PRC), India, Indonesia, Malaysia, Pakistan, Thailand, and Viet Nam. A description of the variables is provided in Table 1.

2.1 Dependent Variable: GHG Emissions

To measure a firm's emissions, we use two variables: (i) absolute GHG emissions and (ii) GHG emission intensity (the ratio of the firm's GHG emissions to its revenue). For each of these dependent variables, we use two proxies for GHG emissions: (1) direct emissions and (2) direct and indirect (including from supply chain) emissions. Direct emissions include GHG emissions directly generated from sources that the enterprise owns or controls, such as emissions from fossil fuels combusted by the firm and manufacturing processes. Indirect emissions, on the other hand, come from sources that are not owned or directly controlled by the enterprise but are closely linked to its activities (e.g., from suppliers). Specifically, indirect emissions include emissions that arise from the company's direct suppliers, such as emissions arising when electricity is consumed by the firm but sourced from a coal-based power plant and emissions arising from employees' business air travel and commuting. Thus, firms' GHG emissions are measured using four dependent variables.

2.2 Explanatory Variable: Fossil Fuel Subsidy

One of the most significant concerns about fossil fuel subsidies is their contribution to climate change and environmental degradation. Subsidies make fossil fuels cheaper, encouraging greater consumption (Figure 2) and discouraging investments in low-carbon technologies (such as renewable energy and energy efficiency), and thus they increase greenhouse gas emissions. This undermines global efforts to combat climate change and causes harm to health through air pollution.

Fuel subsidies are usually provided to fuel producers or consumers in order to lower the price of fuel. The funding of subsidies is a burden on public expenditure, but subsidies are not always visible. Fuel subsidies are not only explicit (when budgetary resources are used to make a direct cash transfer to a producer or a consumer, or when publicly owned refineries and oil marketing companies are mandated to sell below the cost of production with their losses being covered by budgetary funds) but can also be implicit (ADB 2016). Implicit (or off-budget) subsidies are often "hidden"/"invisible" and difficult to calculate or measure. Implicit subsidies have no direct budgetary impact and resemble more of an opportunity cost or the absent revenue that would have been raised if energy consumers had paid the full energy price. Implicit subsidies are provided when, for example, the energy price is as low as the marginal energy production cost and below the average energy production cost (which occurs if there are regulated or controlled energy prices). Such a low price does not account for infrastructure amortization and the replacement of worn-out equipment. For this reason, fuel subsidies are usually estimated using reference energy prices and energy consumption in order to account for both explicit and implicit subsidies.

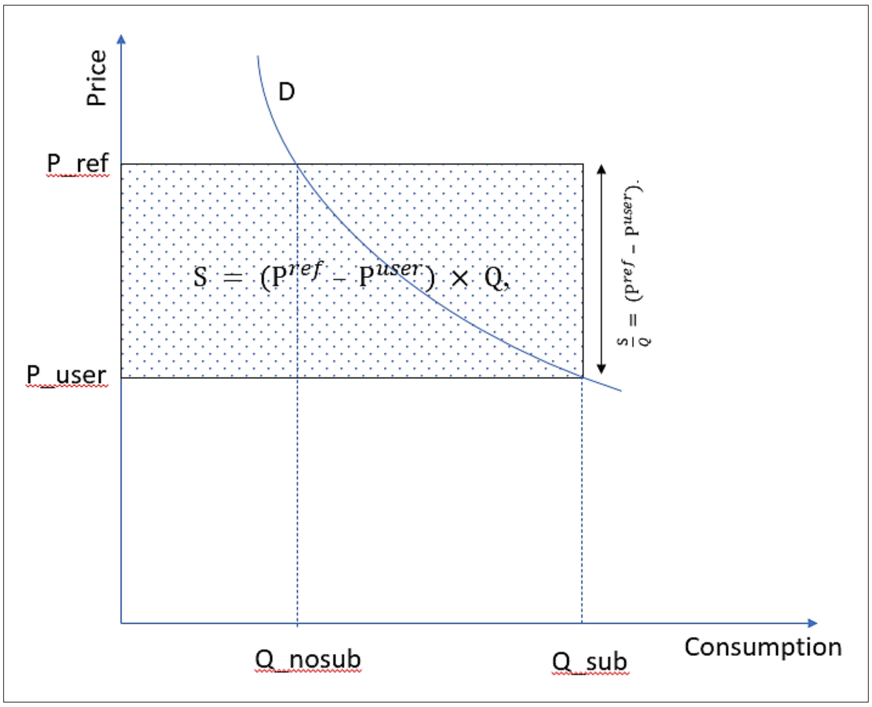
Table 1: Variable Definitions and Descriptive Statistics

Variable	Unit	Definition	Source	Mean	SD	Min	Max
Absolute GHG emissions (direct emissions)	log(tCO2e)	Natural logarithm of firm's GHG emissions	Environment package of S&P Capital IQ Pro	10.067	2.943	–5.494	19.839
GHG emission intensity (direct emissions)	log(tCO2e/US$M)	Firm's GHG emissions divided by its revenue (natural logarithm)	Environment package of S&P Capital IQ Pro	3.483	2.290	–6.341	10.816
Absolute GHG emissions (direct and indirect emissions)	log(tCO2e)	Natural logarithm of firm's GHG emissions	Environment package of S&P Capital IQ Pro	11.478	2.456	–3.617	19.881
GHG emission intensity (direct and indirect emissions)	log(tCO2e/US$M)	Firm's GHG emissions divided by its revenue (natural logarithm)	Environment package of S&P Capital IQ Pro	4.893	1.682	0.862	10.824
Total subsidy per unit of energy consumption	US$M/Mtoe	Total fossil fuel subsidy divided by total energy consumption	IEA & Enerdata	26.787	30.565	1.189	206.698
Oil subsidy per unit of energy consumption	US$M/Mtoe	Oil subsidy divided by oil consumption	IEA & Enerdata	61.702	68.989	0	398.308
Gas subsidy per unit of energy consumption	US$M/Mtoe	Gas subsidy divided by gas consumption	IEA & Enerdata	9.679	20.757	0	275.158
Electricity subsidy per unit of energy consumption	US$M/Mtoe	Electricity subsidy divided by electricity consumption	IEA & Enerdata	189.332	249.600	0	1,979.796
Total subsidy as a share of GDP	Ratio (basic point)	Total fossil fuel subsidy divided by GDP	IEA & Enerdata	76.444	83.520	3.205	517.833
Oil subsidy as a share of GDP	Ratio (basic point)	Oil subsidy divided by GDP	IEA & Enerdata	47.130	62.870	0	389.628
Gas subsidy as a share of GDP	Ratio (basic point)	Gas subsidy divided by GDP	IEA & Enerdata	3.882	16.795	0	319.938
Electricity subsidy as a share of GDP	Ratio (basic point)	Electricity subsidy divided by GDP	IEA & Enerdata	24.918	26.176	0	239.957
Firm size	log(US$M)	Natural logarithm of firm's total assets	S&P Capital IQ Pro	14.385	1.595	2.086	21.099
Financial leverage	Ratio	Total liability divided by total assets	S&P Capital IQ Pro	0.514	0.225	0.053	1.010
Return on assets	Ratio	Firm's return relative to its total assets	S&P Capital IQ Pro	0.050	0.078	–0.292	0.310
Firm age	log (years)	Number of years since firm's foundation (natural logarithm)	S&P Capital IQ Pro	3.383	0.624	0	6.084
Revenue growth	Ratio	The annual growth rate of revenue	S&P Capital IQ Pro	0.139	0.382	–0.600	2.884

Notes: tCO2e = metric tons of carbon dioxide equivalent, Mtoe = millions of metric tons of oil equivalent, US$M = thousand US Dollars, SD = standard deviation, N = number of observations =17,815.

Source: authors' compilation.

Figure 2: Fossil Fuel Subsidy and Energy Consumption



Notes: P_user = end-user price, P_ref = reference price, Q_sub = energy consumption with subsidy, Q_nosub = energy consumption without subsidy, S = subsidy, S/Q = subsidy per unit of energy. The shaded area demonstrates the amount of subsidy in monetary units (e.g., USD).

Fossil fuel subsidies in this paper are those estimated by the International Energy Agency (IEA). The IEA provides data on annual fossil fuel subsidies from 2010 by country and by fuel (electricity, crude oil and gas), measured in USD. The IEA estimates fossil fuel consumption subsidies using the fuel consumption of end-users and those who consume as inputs to electricity generation. IEA uses the price-gap methodology[4] (the most commonly used methodology for quantifying consumption subsidies), according to which a subsidy is measured as the gap between the reference price, which corresponds to the full cost of supply, and the end-user price, multiplied by the units of energy consumed for the respective fuel (electricity, crude oil, and gas consumption):

$$S = (P^{ref} - P^{user}) \times Q,$$

where *S* is the estimated fossil fuel subsidy, P^{ref} is the reference price per unit of energy, P^{user} is the end-user price per unit of energy and *Q* is the units of energy consumed.

[4] The price-gap methodology "compares average end-user prices paid by consumers with reference prices that correspond to the full cost of supply. The price gap is the amount by which an end-use price falls short of the reference price and its existence indicates the presence of a subsidy… Subsidy = (Reference price – End-user price) × Units consumed" (IEA https://www.iea.org/topics/energy-subsidies#methodology-and-assumptions).

Estimated fossil fuel subsidies could increase even without a decline in the end-user price or any other action from government. Subsidies could increase as a result of a reference price[5] increase, because implicit subsidies have no direct budgetary impact. Thus, subsidies could increase even without any action from government.

Subsidies could also change as a result of a change in energy consumption. For the purposes of this paper, it is better to measure the fossil fuel subsidy per unit of energy to avoid the impact of energy consumption change: $\frac{S}{Q} = (\mathrm{P}^{ref} - \mathrm{P}^{user})$. Information on energy consumption, which is measured in millions of metric tons of oil equivalent (Mtoe), is obtained from Enerdata. To further validate our results, we also use, as an alternative variable, subsidies per GDP.

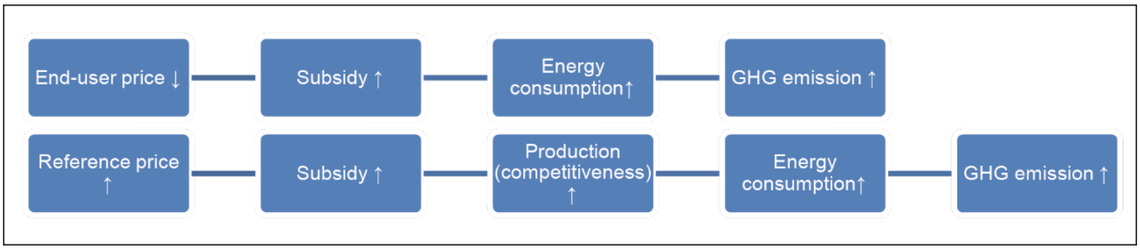
Fossil fuel subsidies per unit of energy can affect firms' GHG emissions through their impact on the end-user price or on the reference price of fossil fuel. The reduction of fossil fuel subsidies via an increase in end-user price should incentivize firms[6] to use low-carbon substitutes (such as renewable energy), improve their energy efficiency, and change their behavior to reduce fossil fuel consumption, which could lead to a reduction in fossil fuel consumption intensity (per unit of output or revenue) and thus in GHG emission intensity. However, a subsidy reduction might not have an impact on emission reduction due to several reasons. For example, due to a switch to relatively cheaper but more polluting fuels (e.g., switch from electricity to coal or diesel); non-energy emissions; and due to the lack of low-emission substitutes, especially in the hard-to-abate sectors (e.g. steel and cement) in which renewable electricity cannot replace fossil fuels because of the need for high temperatures which are hard to achieve using renewable energy. Some sectors have a the lack of low-carbon substitutes in the hard-to-abate sectors (e.g., steel and cement) in which renewable electricity cannot replace fossil fuels because of the need for high temperatures which are hard to reach using renewable energy. Green hydrogen could be a substitute for fossil fuel in hard-to-abate sectors, but it is still a less mature technology (compared to renewable energy), with a cost well above the cost of fossil fuel (Azhgaliyeva, Seetharam and Zhang, 2023). Also, fossil fuel subsidies cannot affect non-energy emissions (from construction material production, agriculture, etc.) (Azhgaliyeva and Rahut 2022). Thus, the impact of subsidy reductions on emissions will vary by sector depending on the availability of low-carbon substitutes and the share of non-energy emissions. The impact of subsidies on emissions is expected to be smaller in hard-to-abate sectors and sectors with non-energy emissions (such as the construction material production and agriculture sectors).

If subsidies were increased because the reference price increased (for example due to an international energy price increase as happened in 2022) then, although the international energy price and reference price are not observable for firms, firms in countries enjoying a subsidized energy price would become more competitive than those in countries without energy subsidies, which could lead to a production increase and thus to greater energy consumption and greater GHG emissions (Figure 3).

[5] The reference price is calculated by the IEA for fuels on the basis of international prices differently for energy net exporters and net importers and with a separate methodology for electricity because it is different from crude oil, natural gas and coal. For more information about the reference price calculation methodology, please refer to https://www.iea.org/topics/energy-subsidies#methodology-and-assumptions.

[6] Additionally, the influence extends to households; however, given the scope of this paper, our primary focus will center on examining the ramifications on firms.

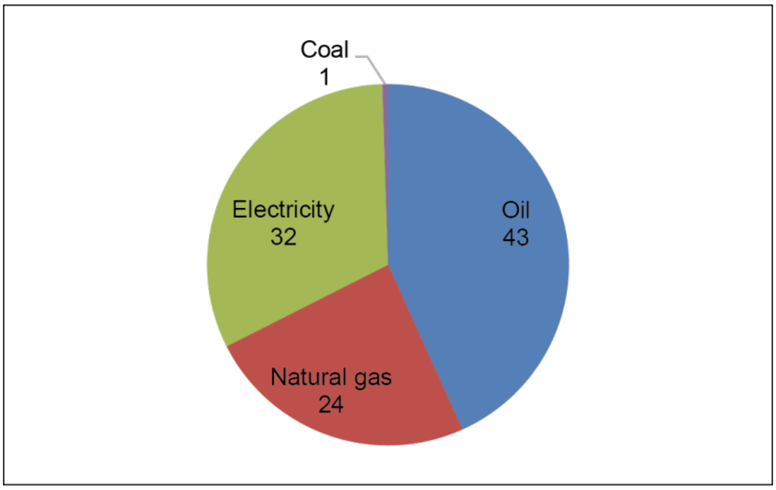
Figure 3: The Impact of Fossil Fuel Subsidies on Firms' GHG Emissions



Unfortunately, data on firm-level subsidies are not available. It was not possible to estimate firms' subsidies using energy consumption because of a lack of data on firm-level energy consumption from developing Asia. For the above reason, we use country-level subsidies.

In this paper, we use country-level annual subsidies for electricity, crude oil and gas, which are 99% of energy subsidies globally. Coal subsidies are excluded as they are very small – less than 1% (Figure 4).

Figure 4: Subsidies by Energy Type 2010–2022(E)
(%)



Notes: 2022(e) denotes 2022 estimates.

Source: Authors, using data from IEA 2023; Fossil Fuels Consumption Subsidies 2022, https://www.iea.org/reports/fossil-fuels-consumption-subsidies-2022, License: CC BY 4.0.

2.3 Control Variables

To examine how fossil fuel subsidies affect firms' GHG emissions, we employ several firm characteristics as control variables. These variables include firm size (computed as the natural logarithm of the firm's total assets), firm leverage (calculated as the ratio of total liabilities to total assets), firm profitability (measured as the ratio of returns to total assets), firm age (proxied by the natural logarithm of the number of years since the firm was established), and revenue growth (calculated as the ratio of current revenue to its value lagged by one). In addition, we account for individual and year–country fixed effects.

3. RESEARCH METHODOLOGY

3.1 Baseline Regressions

To investigate the effect of fossil fuel subsidies on a firm's GHG emissions, we present the following econometric models:

$$ghg_{i,t} = \alpha_0 + \alpha_1\, subsidy_t + \boldsymbol{\gamma}'\boldsymbol{X} + \eta_i + \eta_{c,t} + \varepsilon_{i,t}, \quad (1)$$

where $ghg_{i,t}$ denotes enterprise *i*'s GHG emissions in year *t*. In this study, we employ both absolute GHG emissions and GHG emission intensity (GHG emissions relative to the firm's revenue) as two alternative proxies for a firm's GHG emissions. $subsidy_t$ denotes the fossil fuel subsidy, which is measured as the subsidy per unit of energy and the subsidy as a share of GDP for each type of energy: total, electricity, oil, and gas. $\boldsymbol{X}$ indicates a set of firm characteristics as control variables, which include financial leverage $lev_{i,t}$, revenue growth $rev\_growth_{i,t}$, firm age $age_{i,t}$, firm size $size_{i,t}$, and firm profitability $roa_{i,t}$. We also incorporate individual fixed effects η_i and year–country fixed effects $\eta_{c,t}$ in this baseline model. α_0, α_1, and $\boldsymbol{\gamma}$ are unknown parameters and $\varepsilon_{i,t}$ is an error term.

As a robustness check for our results, we also investigate the effects of fossil fuel subsidies on an enterprise's GHG emissions when both direct and indirect emissions are incorporated:

$$ghg\_both_{i,t} = \alpha_0 + \alpha_1\, subsidy_t + \boldsymbol{\gamma}'\boldsymbol{X} + \eta_i + \eta_{c,t} + \varepsilon_{i,t}. \quad (2)$$

Here, $ghg\_both_{i,t}$ denotes firm *i*'s direct and indirect GHG emissions in year *t*. We employ absolute GHG emissions as well as GHG emission intensity.

3.2 Regressions with Lags

There might be a one-year lag in the response of a firm's GHG emissions to a fossil fuel subsidy. Therefore, this study also investigates the effects of a lagged subsidy on a firm's emissions. Specifically, we estimate the following econometric models:

$$ghg_{i,t} = \alpha_0 + \alpha_1\, subsidy_{t-1} + \boldsymbol{\gamma}'\boldsymbol{X} + \eta_i + \eta_{c,t} + \varepsilon_{i,t}, \quad (3)$$

$$ghg\_both_{i,t} = \alpha_0 + \alpha_1\, subsidy_{t-1} + \boldsymbol{\gamma}'\boldsymbol{X} + \eta_i + \eta_{c,t} + \varepsilon_{i,t}. \quad (4)$$

Here, $subsidy_{t-1}$ denotes the fossil fuel subsidy in year *t–1*. Similarly, we use the subsidy for each energy type: total subsidy, electricity subsidy, oil subsidy, and gas subsidy. Note also that the control variables $\boldsymbol{X}$ are now evaluated at *t–1*.

4. EMPIRICAL RESULTS: IMPACT OF FOSSIL FUEL SUBSIDIES ON FIRMS' GHG EMISSIONS

4.1 Fossil Fuel Subsidies per Unit of Energy Consumption

This subsection provides the estimated effects of fossil fuel subsidies (per unit of energy consumption) on firms' GHG emissions. The results for absolute GHG emissions and GHG emission intensity are presented separately.

4.1.1 Absolute GHG Emissions

We first investigate the impacts of fossil fuel subsidies on the absolute GHG emissions of enterprises. Table 2 presents the estimated results for the four different subsidies. Overall, we find that fossil fuel subsidies significantly increase a firm's absolute GHG emissions, irrespective of the fossil fuel subsidy utilized. For instance, the estimated coefficient for total subsidy is 0.069 and is statistically significant at the 1% level, demonstrating that for every one unit (US$M/Mtoe) increase in subsidy per unit of energy consumption, a firm's GHG emissions rise by 6.9%. This finding aligns with the existing literature, which demonstrates a positive correlation between elevated levels of fossil fuel subsidies and increased emissions (Arzaghi and Squalli, 2023). Similarly, we observe statistically positive impacts of electricity subsidies and gas subsidies on a company's absolute GHG emissions. Notably, across the subsidies by energy type (crude oil, gas, and electricity), the estimated impact of crude oil subsidies (per unit of oil consumption) is the most pronounced. To be precise, a 1$M/Mtoe increase in oil subsidy per unit of oil consumption leads to a statistically significant 17.1% rise in the company's emission; which is nearly twice as much as the 9.7% rise with a gas subsidy. This difference could be due to the varying GHG emission levels per unit of energy consumed across the energy sources. Combustion of crude oil emits more GHG emissions than combustion of gas. According to the IEA (2017), for each unit of energy output, CO_2 emissions resulting from gas combustion are roughly 20% less than those originating from oil. The impact of an oil subsidy is notably more pronounced than that of a gas subsidy because, for the same energy consumption, an increase in crude oil consumption will cause more GHG emissions than an increase in natural gas consumption. This heightened impact can be attributed to the higher GHG emissions caused by the consumption of crude oil. In contrast, gas exhibits relatively smaller effects on emissions when subsidized.

It is also worth mentioning that our results are consistent with the previous literature on why the removal of fossil fuel subsidies is necessary for a reduction in emissions. The rationale is that these subsidies disrupt the market price signal, ultimately resulting in escalated levels of energy consumption, increased production, and elevated pollution emissions (Jewell et al. 2018; Jiang and Tan 2013; Liang, Zhang, and Qiang 2022). In addition, Cockburn, Robichaud, and Tiberti (2018) demonstrate that fossil fuel subsidies can impede the availability of subsidies for emerging clean energy services, posing a hindrance to the adoption of these clean energy sources.

Table 2: Subsidy per Unit of Energy Consumption—Absolute GHG Emissions
(Mtoe)

Absolute GHG Emissions	(1) Total	(2) Electricity	(3) Oil	(4) Gas
Total subsidy	0.069***			
	(0.015)			
Firm size	0.754***	0.754***	0.754***	0.754***
	(0.081)	(0.081)	(0.081)	(0.081)
Leverage	0.245	0.245	0.245	0.245
	(0.179)	(0.179)	(0.179)	(0.179)
Return on assets	1.349***	1.349***	1.349***	1.349***
	(0.209)	(0.209)	(0.209)	(0.209)
Firm age	0.057	0.057	0.057	0.057
	(0.187)	(0.187)	(0.187)	(0.187)
Revenue growth	0.138***	0.138***	0.138***	0.138***
	(0.029)	(0.029)	(0.029)	(0.029)
Electricity subsidy		0.002***		
		(0.000)		
Oil subsidy			0.171***	
			(0.037)	
Gas subsidy				0.097***
				(0.021)
Constant	–3.468***	–1.998*	–11.484***	–2.471**
	(1.277)	(1.203)	(2.489)	(1.218)
Year country FE	Yes	Yes	Yes	Yes
Observations	17,815	17,815	17,815	17,815
R-squared	0.160	0.160	0.160	0.160
Number of companies	3,359	3,359	3,359	3,359

Notes: *** p < 0.01, ** p < 0.05, * p < 0.1. Robust standard errors in parentheses.
Source: Authors' own calculations.

Note also that two commonly employed statistical tests, namely the Breusch and Pagan Lagrangian Multiplier (LM) test and the Hausman specification test, are conducted in this study with the objective of ascertaining the most appropriate research framework among pooling, random effects, and fixed-effects models. Initially, a comprehensive examination of the LM test reveals that the chi-square statistics reject the null hypothesis, thereby affirming the existence of individual effects at a statistically significant level of 1% irrespective of the fossil fuel subsidy utilized. Consequently, the incorporation of the individual effect is deemed imperative for the empirical analysis. Subsequently, the application of the Hausman specification test is employed to facilitate a comparative analysis between the random effects model and the fixed-effects model. The results substantiate the superior suitability of the fixed-effects model in examining the impacts of fossil fuel subsidies on firms' emissions.

4.1.2 GHG Emission Intensity

We further explore how fossil fuel subsidies affect the GHG emission intensity of enterprises (in order to eliminate the impact of changes in energy consumption). The results are presented in Table 3. In general, we find that fossil fuel subsidies increase firms' GHG emission intensities. The estimated coefficient for total subsidy is 0.067 and is statistically significant, indicating that a firm's GHG emission intensity rises by 6.7%

when the subsidy per unit of energy consumption increases by 1 US$M/Mtoe. As before, comparing subsidies across the energy types, the estimated effect of an oil subsidy on a company's GHG emission intensity is larger than the effects for electricity and gas. Specifically, a 1 US$M/Mtoe rise in oil subsidy per unit of oil consumption yields a statistically significant increase of 16.6% in the company's emission intensity, comparing to a 9.4% rise for a gas subsidy and 0.1% for an electricity subsidy. The potential explanation is that oil is more polluting per unit of energy than gas and electricity; thus, the impact of an oil subsidy is higher than the impacts of electricity and gas subsidies.

Table 3: Subsidy per Unit of Energy Consumption—GHG Emission Intensity

GHG Emission Intensity	(1) Total	(2) Electricity	(3) Oil	(4) Gas
Total subsidy	0.067***			
	(0.015)			
Firm size	0.023	0.023	0.023	0.023
	(0.029)	(0.029)	(0.029)	(0.029)
Leverage	-0.052	-0.052	-0.052	-0.052
	(0.107)	(0.107)	(0.107)	(0.107)
Return on asset	0.028	0.028	0.028	0.028
	(0.128)	(0.128)	(0.128)	(0.128)
Firm age	0.003	0.003	0.003	0.003
	(0.138)	(0.138)	(0.138)	(0.138)
Revenue growth	–0.010	–0.010	–0.010	–0.010
	(0.017)	(0.017)	(0.017)	(0.017)
Electricity subsidy		0.001***		
		(0.000)		
Oil subsidy			0.166***	
			(0.036)	
Gas subsidy				0.094***
				(0.021)
Constant	1.022	2.449***	–6.759***	1.990***
	(0.734)	(0.592)	(2.247)	(0.624)
Year country FE	Yes	Yes	Yes	Yes
Observations	17,815	17,815	17,815	17,815
R-squared	0.017	0.017	0.017	0.017
Number of companies	3,359	3,359	3,359	3,359

Note: *** p < 0.01, ** p < 0.05, * p < 0.1. Robust standard errors in parentheses.

Source: Authors' own calculations.

4.2 Fossil Fuel Subsidies as a Share of GDP

To validate our results, we use a different measure of subsidies—fossil fuel subsidies relative to GDP—and estimate the impacts on firms' GHG emissions using this measure. As in the previous section, we present the estimated results for absolute GHG emissions and GHG emission intensity separately.

We investigate the impacts of fossil fuel subsidies on the absolute GHG emissions (Table 4) and the GHG emission intensity (Table 5). The results are consistent with main results from section 4.1 (Tables 2 and 3). Overall, we find that fossil fuel subsidies significantly increase a firm's absolute GHG emissions. For instance, the estimated coefficient for total subsidy is 0.016 and is statistically significant at 1% level, which means that for every 0.01% increase in total subsidy relative to real GDP, a firm's GHG emissions rise by 1.6%. Similarly, we observe statistically positive impacts of electricity subsidies and gas subsidies on a company's absolute GHG emissions. As before, across energy types, the estimated impact of an oil subsidy (per unit of oil consumption) is higher than that for electricity and gas.

Table 4: Subsidy Relative to GDP (Real)—Absolute GHG Emissions

	(1)	(2)	(3)	(4)
Absolute GHG Emissions	**Total**	**Electricity**	**Oil**	**Gas**
Total subsidy	0.016***			
	(0.004)			
Firm size	0.754***	0.754***	0.754***	0.754***
	(0.081)	(0.081)	(0.081)	(0.081)
Leverage	0.245	0.245	0.245	0.245
	(0.179)	(0.179)	(0.179)	(0.179)
Return on asset	1.349***	1.349***	1.349***	1.349***
	(0.209)	(0.209)	(0.209)	(0.209)
Firm age	0.057	0.057	0.057	0.057
	(0.187)	(0.187)	(0.187)	(0.187)
Revenue growth	0.138***	0.138***	0.138***	0.138***
	(0.029)	(0.029)	(0.029)	(0.029)
Electricity subsidy		0.015***		
		(0.003)		
Oil subsidy			0.112***	
			(0.024)	
Gas subsidy				0.080***
				(0.017)
Constant	–3.044**	–1.810	–63.616***	–2.084*
	(1.248)	(1.199)	(13.520)	(1.205)
Observations	17,815	17,815	17,815	17,815
R-squared	0.160	0.160	0.160	0.160
Number of companies	3,359	3,359	3,359	3,359

Notes: *** p < 0.01, ** p < 0.05, * p < 0.1. Robust standard errors in parentheses.

Source: Authors' own calculations.

Table 5: Subsidy Relative to GDP (Real)—GHG Emission Intensity

GHG Emission Intensity	(1) Total	(2) Electricity	(3) Oil	(4) Gas
Total subsidy	0.016***			
	(0.003)			
Firm size	0.023	0.023	0.023	0.023
	(0.029)	(0.029)	(0.029)	(0.029)
Leverage	–0.052	–0.052	–0.052	–0.052
	(0.107)	(0.107)	(0.107)	(0.107)
Return on asset	0.028	0.028	0.028	0.028
	(0.128)	(0.128)	(0.128)	(0.128)
Firm age	0.003	0.003	0.003	0.003
	(0.138)	(0.138)	(0.138)	(0.138)
Revenue growth	–0.010	–0.010	–0.010	–0.010
	(0.017)	(0.017)	(0.017)	(0.017)
Electricity subsidy		0.014***		
		(0.003)		
Oil subsidy			0.109***	
			(0.024)	
Gas subsidy				0.077***
				(0.017)
Constant	1.434**	2.632***	–57.360***	2.366***
	(0.681)	(0.584)	(13.341)	(0.597)
Observations	17,815	17,815	17,815	17,815
R-squared	0.017	0.017	0.017	0.017
Number of companies	3,359	3,359	3,359	3,359

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Robust standard errors in parentheses.

Source: Authors' own calculations.

5. ROBUSTNESS CHECKS

To further validate our key findings, we carry out robustness checks. First, we investigate the effects of a lagged fossil fuel subsidy on an enterprise's GHG emissions. Second, we check the impact of a fossil fuel subsidy on a firm's direct and indirect GHG emissions.

5.1 Impacts of Lagged Fossil Fuel Subsidy on Firm's Emissions

There might be a lag in the response of a firm's GHG emissions to a fossil fuel subsidy. Therefore, this section provides the estimated effects of lagged fossil fuel subsidies on firms' emissions. The results are presented in Table 6. Overall, our key findings remain unchanged. Specifically, we find that lagged fossil fuel subsidies increase firms' absolute GHG emissions irrespective of the fossil fuel subsidy utilized. For instance, the estimated coefficient for total subsidy is 0.014 and this is statistically significant at the 1% level, which demonstrates that for every 1% increase in total subsidy per unit of total energy consumption, a firm's absolute GHG emissions rise by 1.4%. Similarly, we demonstrate that across energy types (crude oil, electricity and gas), the estimated impact of a lagged oil subsidy (per unit of oil consumption) is the most pronounced, staying at 0.553. Note that, although we do not report the results here, we obtain similar findings for GHG emission intensity.

Table 6: Effects of Lagged Fossil Fuel Subsidies on Firms' GHG Emissions—Absolute Emissions

Absolute GHG Emissions	(1) Total	(2) Electricity	(3) Oil	(4) Gas
Total subsidy (lag)	0.014***			
	(0.004)			
Firm size (lag)	0.532***	0.532***	0.532***	0.532***
	(0.084)	(0.084)	(0.084)	(0.084)
Leverage (lag)	0.344**	0.344**	0.344**	0.344**
	(0.156)	(0.156)	(0.156)	(0.156)
Return on asset (lag)	1.397***	1.397***	1.397***	1.397***
	(0.203)	(0.203)	(0.203)	(0.203)
Firm age (lag)	–0.049	–0.049	–0.049	–0.049
	(0.179)	(0.179)	(0.179)	(0.179)
Revenue growth (lag)	0.164***	0.164***	0.164***	0.164***
	(0.024)	(0.024)	(0.024)	(0.024)
Electricity subsidy (lag)		0.001***		
		(0.000)		
Oil subsidy (lag)			0.553***	
			(0.143)	
Gas subsidy (lag)				0.022***
				(0.006)
Constant	1.813	1.833	–31.121***	1.980*
	(1.178)	(1.178)	(8.680)	(1.175)
Observations	17,371	17,371	17,371	17,371
R-squared	0.117	0.117	0.117	0.117
Number of companies	3,356	3,356	3,356	3,356

Note: *** p < 0.01, ** p < 0.05, * p < 0.1. Robust standard errors in parentheses.

Source: Authors' own calculations.

5.2 Impacts of Fossil Fuel Subsidy on Firms' Emissions: Direct and Indirect Emissions

As a further robustness check, we provide the estimated effects of fossil fuel subsidies on firms' emissions when both direct and indirect emissions are taken into consideration. The results are presented in Table 7. Overall, our key findings remain virtually unchanged. Specifically, we find that fossil fuel subsidies increase firms' absolute GHG emissions. For instance, the estimated coefficient for total subsidy is 0.028 and is statistically significant at the 1% level, which means that for every 1% increase in total subsidy relative to the total energy consumption, a firm's absolute GHG emissions rise by 2.8%. Similarly, we observe that across the energy types, the estimated impact of oil subsidy (per unit of oil consumption) is the highest, at 0.070. Note that, although we do not report the results here, we obtain similar findings for GHG emission intensity.

Table 7: Estimated Effects of Fossil Fuel Subsidies on Firms' Absolute GHG Emissions—Direct and Indirect Emissions

Absolute GHG Emissions	(1) Total	(2) Electricity	(3) Oil	(4) Gas
Total subsidy	0.028***			
	(0.010)			
Firm size	0.790***	0.790***	0.790***	0.790***
	(0.080)	(0.080)	(0.080)	(0.080)
Leverage	0.184	0.184	0.184	0.184
	(0.154)	(0.154)	(0.154)	(0.154)
Return on asset	1.313***	1.313***	1.313***	1.313***
	(0.182)	(0.182)	(0.182)	(0.182)
Firm age	0.080	0.080	0.080	0.080
	(0.155)	(0.155)	(0.155)	(0.155)
Revenue growth	0.144***	0.144***	0.144***	0.144***
	(0.026)	(0.026)	(0.026)	(0.026)
Electricity subsidy		0.001***		
		(0.000)		
Oil subsidy			0.070***	
			(0.025)	
Gas subsidy				0.040***
				(0.014)
Constant	–1.378	–0.774	–4.674**	–0.968
	(1.179)	(1.145)	(1.864)	(1.152)
Observations	17,815	17,815	17,815	17,815
R-squared	0.262	0.262	0.262	0.262
Number of companies	3,359	3,359	3,359	3,359

Notes: *** p < 0.01, ** p < 0.05, * p < 0.1. Robust standard errors in parentheses.

Source: Authors' own calculations.

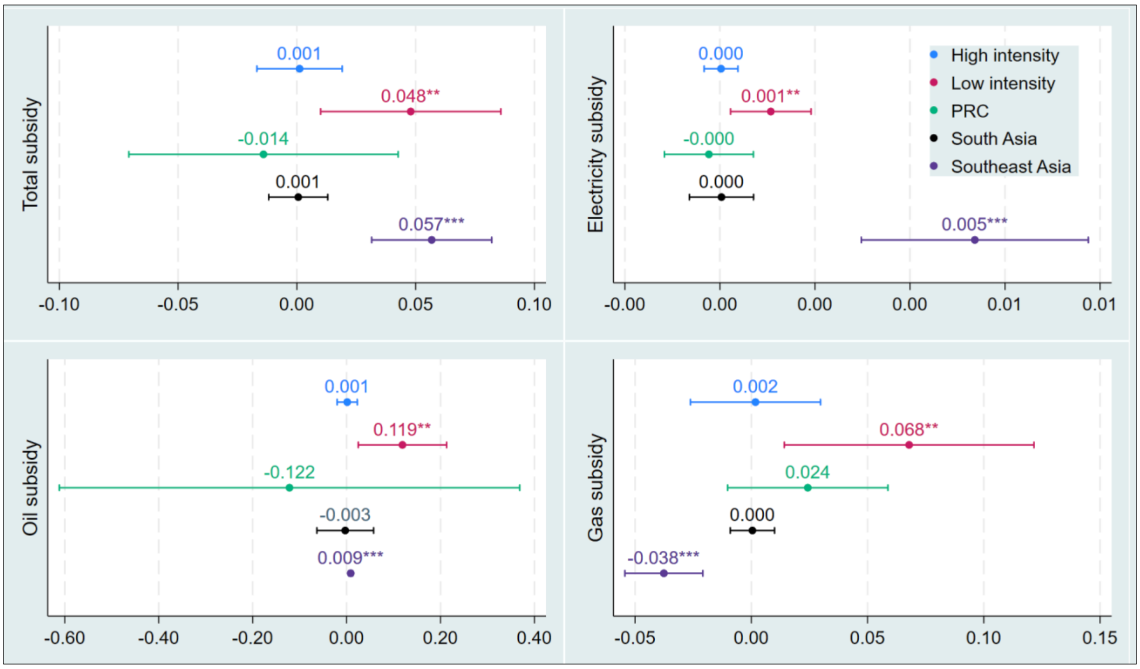
5.3 Heterogenous Effects

In this section, we examine the heterogenous effects of fossil fuel subsidies across regions and sectors. For sectors, we divide the companies into two groups by sector: (i) high energy consumption including the Energy, Industrials, Materials, and Utilities sectors and (ii) low energy consumption including the Communication Services, Consumer Discretionary, Consumer Staples, Financials, Health Care, Information Technology, and Real Estate sectors. For regions, we divide into sub-regions: (i) PRC, (ii) South Asia (India and Pakistan), and (iii) Southeast Asia (Indonesia, Malaysia, Thailand, and Viet Nam). The estimated results for the heterogenous effects are displayed in Figures 5 and 6. Overall, we observe heterogenous effects across regions and sectors.

First, comparing regions, while fossil fuel subsidies have a positive impact on firms' GHG emissions in Southeast Asia, no significant effect is documented for the PRC or South Asia for any type of fossil fuel subsidy. For instance, a 1% increase in total subsidy (per unit of energy consumption) leads to a 5.7% and a 4.7% increase in the absolute GHG emissions and GHG emission intensity, respectively, of firms in Southeast Asia. Similar results are obtained for crude oil, gas and electricity subsidies.

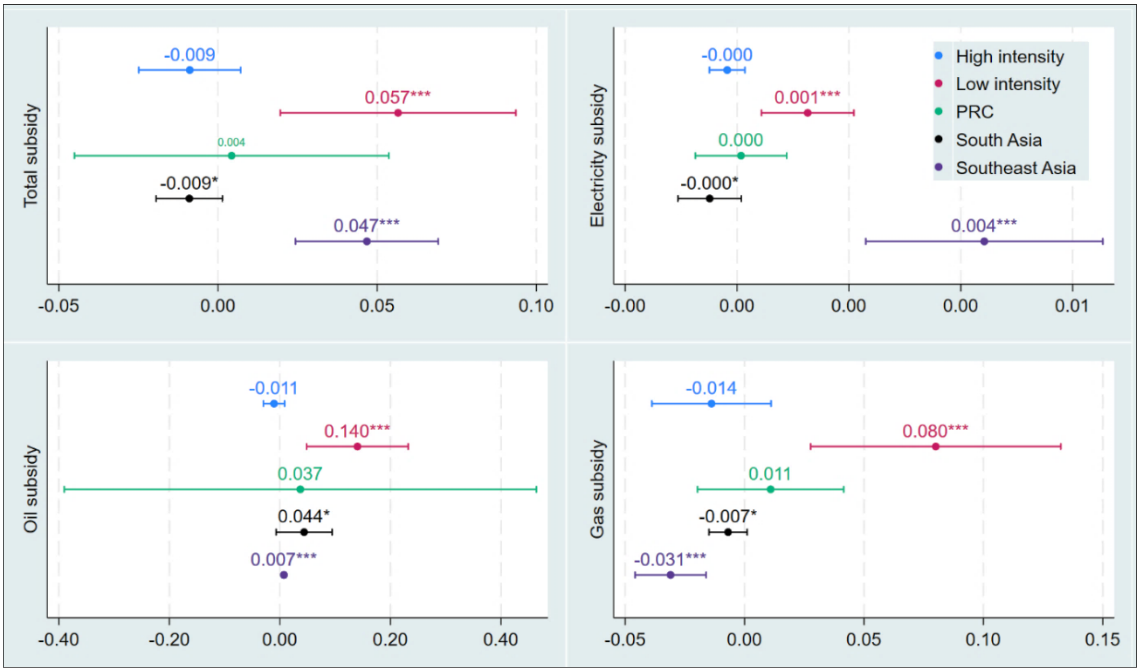
Second, comparing the sector groups, increased subsidies for all types of energy (oil, gas and electricity) increase both the absolute GHG emissions and the GHG emission intensity of firms in the low energy consumption sectors, while no statistically significant changes are observed in the high energy consumption sectors. Let us consider oil subsidies, for instance. A 1% increase in the oil subsidy (per unit of energy consumption) results in an 11.9% and a 14% increase in absolute GHG emissions and GHG emission intensity, respectively, of firms in low energy consumption sectors. In contrast, the GHG emissions of firms in high energy consumption sectors are not affected by changes in oil subsidy. The potential explanation is that firms in sectors with a low energy consumption are more likely to replace fossil fuels with low-carbon energy solutions such as rooftop solar PV, to improve their energy efficiency, and to reduce passive energy consumption such as by having openable windows. However, for sectors with high energy consumption such options could be limited. For utilities, the large-scale replacement of fossil fuel with renewable energy will require sufficient energy storage (the cost of which is very high currently when compared to fossil fuel) and other solutions for dealing with intermittency of renewable energy. Hard-to-abate sectors (industrial and material) also have limited options for replacing fossil fuel, due to their need for high temperatures which cannot be provided by renewable energy. Also, some sectors (such as the industrial and materials sectors) have non-energy emissions, which are not affected by the replacement of fossil fuels with low-carbon energy solutions. Non-energy emissions could only be decreased using carbon capture and storage technology, which is currently very immature and thus expensive.

Figure 5: Heterogenous Effects of Fossil Fuel Subsidies on Absolute GHG Emissions across Sectors and Regions



Notes: High intensity = high energy consumption sectors, low intensity = low energy consumption sectors, PRC = People's Republic of China.

Figure 6: Heterogenous Effects of Fossil Fuel Subsidies on GHG Emission Intensity across Sectors and Regions



Notes: High intensity = high energy consumption sectors, low intensity = low energy consumption sectors, PRC = People's Republic of China.

6. CONCLUSIONS AND POLICY RECOMMENDATIONS

Since the G7 and G20 countries are committed to phasing out fossil fuel subsidies and are calling on other countries to do the same, this paper aims to contribute to the existing literature by providing empirical evidence on the ex-post environmental impact of fossil fuel subsidies at firm-level, since this evidence is very scant for developing Asia. This paper studies the effects of fossil fuel subsidies on firms' GHG emissions using data from seven countries from developing Asia: the PRC, India, Pakistan, Indonesia, Malaysia, Thailand, and Viet Nam. This study utilizes fossil fuel subsidies for electricity, crude oil, and gas. Using data from 3,359 firms over the period 2010–2021 we provide the following key results. Since a reduction in emissions could be due not only to investments in low-carbon substitutes but also to a reduction in production, it is important to study the impact not only on GHG emissions but also on GHG emission intensity, and since changes in fossil fuel subsidies could be due to changes in fossil fuel consumption, it is important to measure the subsidy per unit of energy.

First, we demonstrate that the GHG emissions (both absolute GHG emissions and GHG emission intensity) of firms increase with an increase in fossil fuel subsidies (both absolute and per unit of energy). Subsidies on crude oil have a greater impact on emissions than those on gas. This is because the combustion of crude oil emits more GHG emissions per unit of energy than the combustion of gas.

Second, fossil fuel subsidies affect the emissions of firms in low energy consumption sectors, but have no impact on those in high energy consumption sectors. This could be due to the limited ability of firms in high energy sectors to replace fossil fuel with low-carbon energy solutions, and due to non-energy emissions.

Third, we observe heterogenous effects across regions and sectors. While fossil fuel subsidies positively impact firms' GHG emissions (both absolute GHG emissions and GHG emission intensity) in Southeast Asia, no significant effect is found for the PRC or South Asia. This also could be due to the limited ability of firms in some countries to replace fossil fuel with low-carbon energy solutions, and due to non-energy emissions.

The above results mean that fossil fuel subsidy removal by increasing user price does not guarantee emission reduction. Fossil fuel subsidy removal alone won't be sufficient for emission reduction. Governments are reluctant to remove fossil subsidies by increasing user price because of public pressure and energy poverty. Policy makers have used subsidies in recent years to mitigate the effects of rising energy prices on firms and households. Removing subsidies during these episodes, in the absence of affordable energy alternatives, looks not feasible, given the negative economic consequences. However, the subsidies should be phased out, because fossil fuel subsidies are not sustainable (especially implicit/off-budget subsidies which are provided via low energy prices without accounting for equipment amortization and replacement), and governments need to plan for subsidy reduction/removal and the replacement of subsidies with more targeted and efficient support. Governments can develop well-designed plans to overcome resistance to subsidy removal, for example by educating the public about the need for and the benefits of reduction/removal and by replacing fossil fuel subsidies with more targeted and efficient support where necessary. This paper provides evidence-based policy recommendations on the reduction/removal of fossil fuel subsidies in order to reduce GHG emissions.

First, the reduction of fossil fuel subsidies could reduce GHG emissions in a country. Since subsidies on crude oil have a greater impact on emissions than those on gas and electricity, the reduction of crude oil subsidies will have a greater impact on reducing emissions per unit of energy compared to gas and electricity subsidies.

Second, the reduction of GHG emissions and, most importantly, the reduction of GHG emission intensity is not guaranteed by subsidy reductions. The effectiveness of subsidy reductions on GHG emissions depends on the availability of suitable low-carbon solutions. Thus, it is important that subsidy reduction is accompanied by other policies providing low-carbon solutions. Not all sectors will reduce their emissions as a result of subsidy reductions because of their limited ability to replace fossil fuels with low-carbon energy solutions (such sectors are called hard-to-abate sectors). There is a need for other technologies, which are still immature and expensive, to accommodate low-carbon energy solutions (e.g. energy storage which is needed to accommodate the intermittency of most renewable energy), and firms (such as those in the industrial and agriculture sectors) have non-energy emissions. Non-energy emissions are not affected directly by fossil fuel subsidies as they are not caused by fossil fuel combustion.

As mentioned before, the simple reduction/removal of fossil fuel subsidies will not be sufficient, and the subsidies need to be replaced with more targeted/efficient support. However, this issue is outside the scope of this paper. The authors will try to cover it in their future research.

The main limitations of this study are due to limited data availability. Data on fossil fuel subsidies are estimated by the IEA using the price-gap methodology, which uses a reference price for estimating subsidies rather than the actual subsidies, as the data on actual subsidies is highly limited and most subsidies are off-budget (implicit) because they are made through regulating the energy price. Unfortunately, data on firm-level subsidies are not available. Estimating a firm's subsidies using energy consumption was not possible because of a lack of data on firm-level energy consumption from developing Asia. For the above reasons we used country-level subsidies.

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