TransitionZero

C3PI Methodology Document

Coal-to-Clean Carbon Price Index (C3PI)

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TransitionZero

TransitionZero is a climate analytics not-for-profit established to clarify complexity with data transparency. We do this by developing open data and open source projects to support economic and financial decision making in electricity and industry sectors. The work of TransitionZero has been made possible by the vision and innovation shown by Quadrature Climate Foundation, Generation Investment Management, Google.org, ClimateWorks, European Climate Foundation and Bloomberg Philanthropies.

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The experts above that contributed to this report are not responsible for any opinions or judgments it contains. Any errors and omissions are solely the responsibility of TransitionZero.

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01 Executive Summary

The objective of this report is to detail the methodology of our Coal-to-Clean Carbon Price Index (C3PI). C3PI is a novel metric comparing the carbon price required to switch from existing coal to new dispatchable renewables in 25 countries, representing around 85% of operating coal capacity globally.

Fuel switch costs in electricity have historically been analysed through coal and fossil gas generation prices. Fossil gas has a lower carbon intensity than coal, so if the carbon price gets high enough it becomes more economic to burn gas than coal. This level is termed the fuel switch price. The problem with this metric is it ignores the transformation required for electricity generation to be consistent with the temperature goal in the Paris Agreement. The IEA's net-zero emissions (NZE) scenario underscores the urgency of this transformation: virtually no unabated coal or fossil gas generation by 2035 in advanced economies and globally by 2040. Around 60% of electricity generation came from unabated coal and fossil gas in 2020.

Moreover, despite the increasing magnitude and frequency of fossil fuel price shocks, there are no existing tools that actively track the impact of price volatility on the cost-competitiveness of fossil fuels vis-a-vis clean alternatives. In the absence of this analysis, long-term decisions on fossil plants risk being based on unrealistic assumptions, resulting in inflated asset valuations that do not reflect fuel price volatility and competition from cleaner alternatives, such as renewable energy and battery storage.

For these reasons, we developed C3PI – a new metric which calculates the carbon price required to switch to fossil gas and transition directly to dispatchable renewables. We hope this metric will be a useful proxy to showcase the costs required to leapfrog unabated (i.e. CCS unequipped) fossil gas and transition to carbon-free electricity generation. We see C3PI as a helpful tool for policymakers, investors and civil society looking to evaluate the impact of a carbon price in incentivising the switch to renewable energy plus battery storage.

Beyond providing backward-looking estimates to 2010, C3PI goes a step further to provide a forward-looking assessment based on futures prices. This additional step is important for actionable recommendations for investors, policymakers and other stakeholders. A 24-month time frame was selected as it was the approximate time required to bring online new renewable energy projects globally.

To capture fossil fuel price volatility, the C3PI dashboard will initially be updated weekly for the EU, UK, and US, and monthly for the rest of the world. To compliment the dashboard we also provide an excel download, which is updated on a monthly basis.

02 Introduction

Tracking the economics of the energy transition has never been more important. Since the start of 2020, the world has been gripped by a series of energy crises. These crises started with the COVID-19 pandemic and are now being exacerbated by Russia's invasion of Ukraine. The volatility of energy commodities, particularly fossil fuels, is both a symptom and a cause of uncertainty during these turbulent times. Due to a confluence of global trends, we expect to see fossil fuel price shocks occur more frequently and significantly in the future for two reasons.

1. **Energy transition economics**. The energy transition is a vector for volatility for two reasons. Firstly, despite the Ukraine invasion, we expect investment cycles will continue to shorten as fossil producers remain under pressure from investors and policymakers to avoid stranded assets from overinvestment. Secondly, the capital constraints on fossil fuel production are not being offset by low carbon alternatives, as the financial sector is not diverting enough capital towards these technologies. Given the multi-year development of energy infrastructure projects, this dynamic causes higher prices and energy poverty – despite the well understood deflationary trend in renewable energy and battery storage.
2. **Continued geopolitical tensions.** Increased geopolitical tensions imply trade could be used to support energy security and enforce environmental goals, with fossil fuels and supply chains becoming key battlegrounds. The former is best illustrated by the China-Australia trade war, in which we saw China ban Australian thermal coal imports. A similar case was seen when Nord Stream 2, a fossil gas pipeline from the Russian coast near St Petersburg to Lubmin in Germany, was cancelled amid the Russian invasion of Ukraine in February 2022.

Despite the increasing risk of fossil fuel price shocks, energy markets risk falling back on their reliance on fossil fuels, particularly fossil gas, compromising humanity's ability to avoid dangerous climate change. New fossil fuel projects are being developed based on models that assume stable commodity prices and therefore risk becoming stranded assets if developed on a merchant basis. We are cautiously optimistic the implications of fossil fuel price volatility on energy security will be a boon for low carbon alternatives.

However, no existing tools actively track the economic relationship between fossil fuel volatility and deflationary trends in renewable energy and battery storage. For this reason, we developed C3PI, which tracks the carbon price required to switch from existing coal to dispatchable renewable energy in near-real-time across 25 countries, representing around 85% of operating coal capacity globally. We hope C3PI will help clarify how fossil fuel volatility improves the competitiveness of renewable energy and battery storage, with the intention of minimising the amount of fossil gas used in electricity generation for economic and climate reasons.

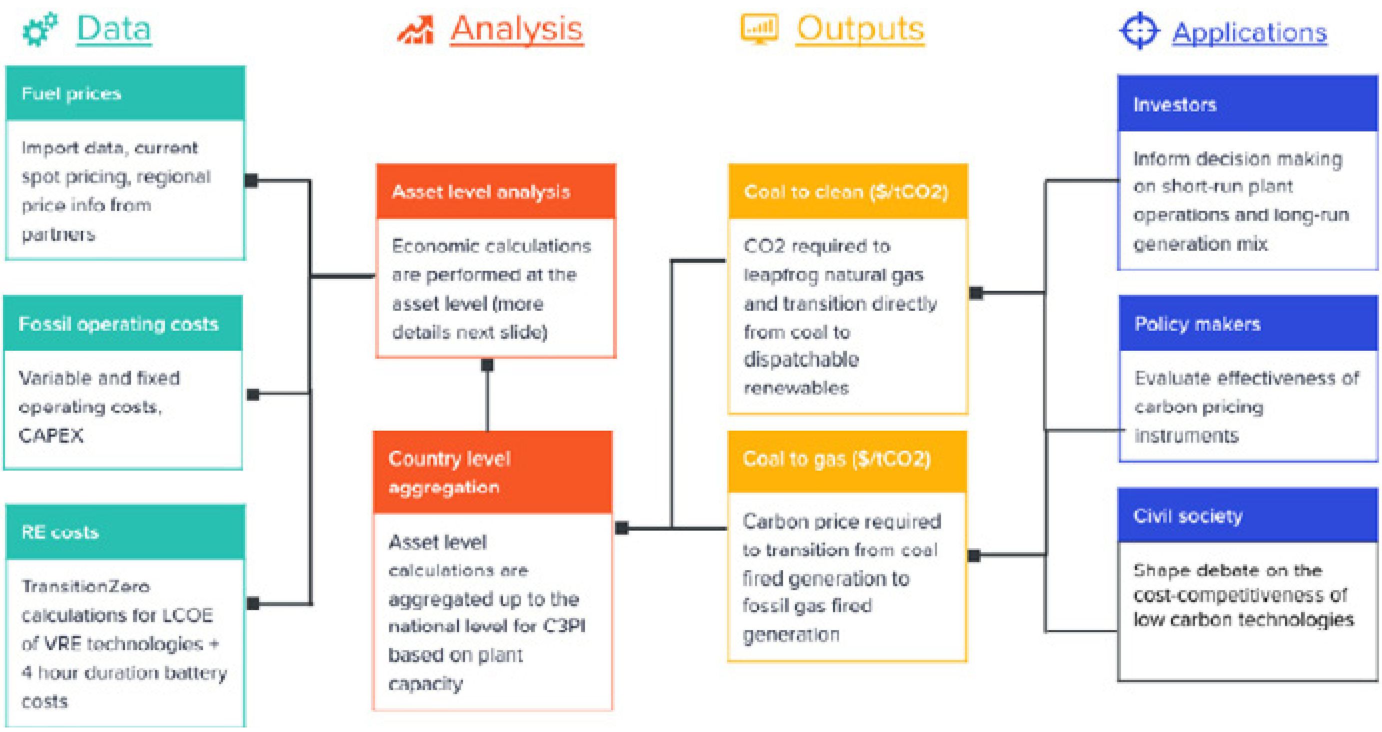
The purpose of this report is to detail the methodology and assumptions underpinning C3PI. The model documentation is broken down into four main sections. The first section defines the metrics and details the technologies used. The second section outlines the model methodology and key assumptions. The third section explains the key limitations associated with this analysis, while the final section highlights some potential use cases by key stakeholders including investors and policymakers, among others.

03 Model

This section outlines C3PI and what it intends to do before explaining the methodology and assumptions used to calculate the fuel switch costs. Historically, fuel switch analysis in electricity generation has primarily been focused on the switch from coal to gas[1]. We have taken this fuel switch analysis a step further by calculating the cost required to leapfrog fossil gas and instead transition directly to dispatchable renewables.

We then extended the analysis to include forecasts covering the next 24 months. The forward–looking analysis is intended to encourage investor action to pursue greenfield renewable energy projects, under the assumption that the cost–competitiveness of renewables will hold steady in the time frame required to bring the project online. Figure 1 below outlines the C3PI model methodology, regional coverage, data outputs and use cases.

Figure 1. Overview of the C3PI model, coverage, and uses



Source: TransitionZero

1 If we are to meet the temperature goals in the Paris Agreement, unabated fossil gas–fired generation will need to be replaced. According to the IEA's Net–Zero Emissions (NZE) scenario, electricity generation needs to be net–zero by 2035 in developed countries and by 2040 globally everywhere else.

Definitions

Table 1. Metrics used in C3PI

Metric	Unit	Description
Coal-to-clean price	$/tCO2	The carbon price on a $/tCO2-basis to trigger a switch from coal generation at existing coal plants to a new-build utility-scale solar photovoltaics (PV) or onshore wind project, coupled with a 4-hour duration battery storage. This decision is triggered when the levelised cost of electricity (LCOE) of the new-build utility-scale solar photovoltaics (PV) or onshore wind project, coupled with battery storage, is lower than the SRMC of coal generation.
Coal-to-gas (existing) price	$/tCO2	The carbon price on a $/tCO2-basis to trigger a fuel switch decision from coal generation at existing coal plants to gas generation at existing gas plants. This fuel switch decision is triggered when the SRMC of gas generation is lower than the SRMC of coal generation.
Coal-to-gas (new build) price	$/tCO2	The carbon price on a $/tCO2-basis to trigger a fuel switch decision from coal generation at existing coal plants to gas generation at new build gas plants. This fuel switch decision is triggered when the LCOE of gas generation is lower than the SRMC of coal generation.
Variable operations & maintenance cost (VOM)	$/MWh	The variable costs associated with operating and upkeep of a plant. This may include long term service agreements (LTSA) for maintenance of power generation units, licensing costs and other consumables including water costs.
Fixed cost (FOM)	$/MWh	The fixed costs associated with operating and upkeep of a plant that does not vary with production. This may include land costs, staff salaries, insurance, cyber security maintenance, among others.
Accrued capital expenditure (CAPEX)	$/MWh	The capital expenditure associated with recouping investment and capital cost of a new-build power plant. This may include engineering, procurement and construction (EPC) costs, land costs, and connection costs, among others.
Short-run marginal cost (SRMC)	$/MWh	Fuel, VOM, and carbon costs (where applicable) of operating a plant. This represents the short-term costs for an operational plant.
Levelised cost of electricity (LCOE)	$/MWh	LCOE represents the average total costs of building and operating a power plant based on per unit of electricity generated over its assumed lifetime. For fossil gas plants, LCOE is the price on a $/MWh basis to recoup project costs and achieve a hurdle rate on its capital investment, and operational costs across the project lifespan, including the short-run marginal cost associated with operating a plant, plus fixed costs. In the case of utility-scale solar PV or onshore wind, coupled with battery storage, this represents the price on an MWh basis to recoup project costs and achieve a required hurdle rate on investment.

Source: TransitionZero

Technologies

Table 2. Power generation technologies and their capital cost components

Technology	Capital expenditure		
	Development costs	Equipment costs	Balance costs
Solar PV	Feasibility studies and environmental permitting	Module and inverters	Cables, transformer, and EPC
Onshore wind	Feasibility studies and environmental permitting	Rotor, drivetrain, nacelle, tower	Assembly and installation
Battery storage	Feasibility studies and environmental permitting	Battery, conversion system	Balancing system, EPC
Coal-fired power plant	n/a	n/a	n/a
Combined cycle gas-fired power plant	Feasibility studies and environmental permitting. This is only for new build gas plants.	Gas turbines, steam turbines. This is only for new build gas plants.	Storage units for gas. This is only for new build gas plants.

Source: TransitionZero

Table 3. Power generation technologies and their operating cost components

Technology	Operating expenditure			
	Fuel	Carbon	Fixed costs	Variable O&M
Solar PV	n/a	n/a	Include operating costs that do not vary with the use of the asset	Include costs that vary with the use of the asset
Onshore wind	n/a	n/a	Include operating costs that do not vary with the use of the asset	Include costs that vary with the use of the asset
Battery storage	n/a	n/a	Include operating costs that do not vary with the use of the asset	Include costs that vary with the use of the asset
Coal-fired power plant	Delivered cost of coal, including fuel, transport, and taxes	Carbon price where applicable	Include operational costs that do not vary with the use of the asset	Include costs that vary with the use of the asset
Combined cycle gas-fired power plant	Delivered cost of gas including fuel, transport, and taxes	Carbon price where applicable	Include operational costs that do not vary with the use of the asset	Include costs that vary with the use of the asset

Source: TransitionZero

Model set up

This section outlines the process implemented to track the following costs:

- Coal-to-clean
- Coal-to-gas (existing)
- Coal-to-gas (new build)

The C3PI is meant to be used as a proxy to track the carbon cost required to transition from coal directly to zero-carbon electricity.

We use country-specific metrics as inputs to develop an economic picture of what is happening at the asset level. The C3PI is meant to be a country level metric, which is derived from an aggregation of asset-level data points weighted by plant capacity. Further documentation of our country-level assumptions is contained in the provided data download. While the asset level data will not be published as part of the C3PI, it will be included as part of our Coal Asset Transition (CAT) tool, which will take a deeper look at the transition of coal power plants at the asset level.

We would also like to highlight that the C3PI is a living index and we are constantly trying to improve the underlying dataset and assumptions. Please note that while this methodology document tries to accurately detail our assumptions at the time of writing, some of the data sources and modelling parameters may change as we work to improve the accuracy of our index and better represent the underlying plant-level economics across the markets we cover.

Fuel switch cost analysis stems from the SRMC of both existing coal and fossil gas plants, and LCOE cost analysis for new build natural gas plants. The C3PI allows users to understand fuel switching based on both short-run perspectives (where existing gas plants can be dispatched to replace coal generation) and long-run perspectives (where new-build gas plants can be built to replace coal generation).

We define the SRMC as the sum of fuel, VOM costs and carbon costs where applicable. The SRMC cost is used to understand the merit order decisions of a plant owner in deregulated markets where units compete for the right to sell power on the wholesale market. In deregulated markets, a plant operator will sell electricity when the wholesale price is above its SRMC.

$$SRMC\ (\$/MWh)\ =\ Fuel\ cost\ (\$/MWh)\ +\ VOM\ (\$/MWh)\ +\ Carbon\ cost\ (\$/MWh)$$

Coal-to-gas (existing) fuel switch is triggered when the SRMC cost of gas is lower than that of coal. Please note that our estimates are considered conservative as it does not include capital additions for maintaining performance or complying with environmental regulations, with the exception of the United States, where going forward capital costs are well documented.

$$Existing\ coal\ to\ existing\ fossil\ \ gas\ (\$/tCO2)\ =\ \frac{Gas\ SRMC\ (\$/MWh) - Coal\ SRMC\ (\$/MWh)}{Coal\ emissions\ intensity\ (tCO2/MWh) - Gas\ emissions\ intensity\ (tCO2/MWh)}$$

In some countries where the existing gas fleet is already operating at full capacity, there is no further opportunity to turn up gas generation to replace coal without building new gas plants. The LCOE metric should be considered under those circumstances. LCOE is a common analytical tool used to compare generation technologies. LCOE is the discounted sum of all the costs incurred during the lifetime of the assets divided by the discounted total of generation. As detailed below, we define LCOE as the accrued capital costs of a new build plant plus SRMC plus FOM costs, which are intended to cover all the costs associated with the construction and operation of a greenfield gas-fired power plant.

$$LCOE\ (\$/MWh) = Accrued\ cost\ of\ capital\ (\$/MWh) + SRMC\ (\$/MWh) + FOM\ (\$/MWh)$$

A coal-to-gas (new build) fuel switch is triggered when the LCOE cost of gas is lower than that of the SRMC of coal, which would indicate that it is cheaper to build a new gas plant to replace existing coal generation.

$$Operating\ coal\ to\ new - build\ fossil\ gas\ (\$/tCO2) = \frac{Gas\ LCOE\ (\$/MWh) - Coal\ SRMC\ (\$/MWh)}{Coal\ emissions\ intensity\ (tCO2/MWh) - Gas\ emissions\ intensity\ (tCO2/MWh)}$$

Renewables plus storage technology is assumed to be able to compete on both the short-run and long-run timescales due to the relatively shorter project development timelines, and is represented using the LCOE metric. LCOE analysis has several limitations, most notably, it only considers generation and fails to account for other values/services to the grid.

For this reason, we pair wind and solar (variable renewable energy - VRE) with battery storage to partially capture the availability or dispatchability provided by coal and gas generation, and flexibility services provided by gas generation. The fuel switch cost then captures the difference in cost associated with the continued operation of fossil fuel plants when compared to the cost associated with building new VRE to replace that generation, while offering comparable services to the grid. This is then divided by the emissions intensity of the fossil fuel to derive the associated fuel switch carbon price.

$$Cost\ to\ switch\ to\ VRE + Storage\ (\$/tCO2) = \frac{LCOE\ of\ VRE + Storage\ (\$/MWh) - Coal\ SRMC\ (\$/MWh)}{Coal\ emissions\ intensity\ (tCO2/MWh)}$$

Given that the cheapest source of VRE varies across countries, we consider the cost to switch from coal to nation-specific lowest cost VRE paired with battery storage. To calculate the lowest cost VRE, we calculate the LCOE of solar PV and onshore wind plus storage for each country separately. The decision on which technology is selected is dictated by whichever VRE technology has the lowest LCOE cost, including the associated battery storage costs, in a particular year for each country. We assume that any new VRE installations will be based on whichever technology is the lowest cost at that point in time.

We defined storage to strictly refer to battery storage. Battery storage can play a variety of roles in the electricity system, from providing ancillary services (including voltage and frequency regulation) to providing grid flexibility through longer duration load shifting. For more information on the various uses of batteries, please refer to ADB's Handbook on Battery Energy Storage System for a detailed discussion.

When paired with VRE, battery storage improves dispatchability of VRE generation, and reduces curtailment risks, while also providing flexibility to the grid. Battery sizing is a critical consideration when pairing VRE with battery storage. Pairing VRE with a battery pack with similar power ratings as the VRE project will result in outsizing battery requirements, as VRE seldom operates at peak load. Instead, downsizing the power rating of the battery pack, as compared to the nameplate capacity of VRE is generally preferred. The duration or energy rating of the battery pack is determined by the purpose it is serving. In the C3PI, battery dimensions are assumed to be half the nameplate capacity of the VRE, with a four-hour duration.

In the future, these same calculations will be performed through the lens of a full system cost analysis, which will be a product of our Future Energy Outlook (FEO)[2]. This full system cost approach will capture the spatial and temporal nature of the electricity, as well as the true market value of each fuel type, which will be an improvement upon the LCOE of VRE technologies.

2 For more information on FEO, see here.

Historical data

This section provides more detail on the assumptions used for each of the key metrics. All assumptions of the model are available to download in excel format.

Fossil plants: capital, operations and maintenance costs

In most cases, capital costs for fossil fuel plants comes from the IEA's World Energy Outlook (WEO), broken out by country and technology type.

In most cases, FOM costs and VOM costs are pulled from the IEA's WEO. While the WEO dataset does not break down operating and maintenance costs into FOM and VOM, we assume that FOM is about 90% of total O&M. As with other input variables, if more granular data is available at the country level, that will be utilised.

Fuel cost: coal price

Coal prices are assigned with as much granularity as possible. Generally, this means coal prices are assigned at the country level. For countries that rely on coal imports, monthly UN Comtrade data is utilised to derive the US $/t paid for coal at a national level. The data from UN Comtrade does not differentiate between different end-sector use.

There are cases when national reporting entities give sector-specific and more up to date information, such as is the case with South Korea, which reports coal prices in the power sector on the national Electric Power Statistics Information System (EPSIS) on a monthly granularity.

In cases where market structure distorts price discovery, such national circumstances are also built into C3PI. In the case of Indonesia, the coal price for power plants is regulated. The national utility, PLN, reports regional coal prices on an annual basis, with some lag in reporting. Regional fuel price metrics are utilised when available to account for variance within a country and are also useful for future asset-level analysis. To deal with lags in data availability, we turn to governmental regulation, historical pricing and current spot price trends to estimate current regulated pricing. This is primarily based on publicly available regulatory decrees. Alongside regulated pricing, we also provide an estimate of where market prices stand in these countries. This gives an indication of the true competitiveness of coal, in the absence of energy subsidies.

If possible, daily coal prices are scraped in real-time and stored in an internal database. This is the case with Rotterdam Coal prices (API 2), which are used for the EU, as well as the EIA weekly coal basin pricing utilised in the US.

Table 4. Coal price methodology

Coal price methodology	Country	Data source	Detaied methodology
Coal pricing indices	EU-27	ICE (API 2)	Coal prices are based on API 2, one-month forward prices.
	UK	ICE (API 2)	Coal prices are based on API 2, one-month forward prices.
National pricing benchmark	China	WIND	Coal prices are based on national statistics.
	India	Ministry of Coal India	Monthly prices as reported by the Ministry of Coal, India. An average of G10-G14 coal grades is used. Where CEA has identified plants that primarily rely on imported coal, UN Comtrade prices are used.
	USA	EIA	Weekly coal pricing by coal basin origin.
Imports-based	Japan	UN Comtrade	Coal prices are based on Japan-reported import statistics, released on UN-COMTRADE.
	Vietnam	UN Comtrade	Coal prices are based on trading partner-reported trade statistics.
	Philippines	UN Comtrade	Coal prices are based on trading partner-reported trade statistics.
	South Korea	EPSIS, KPE	Coal prices are retrieved from EPSIS, with data provided by Korea Power Exchange.
Regulated vs unregulated pricing	Indonesia	PLN, ESDM regulation	Historical regulated coal prices are based on reported pricing by PLN. Current regulated coal prices are retrieved from government regulations and decree.
		UN Comtrade	Unregulated coal prices are retrieved from import statistics.

Source: TransitionZero

Fuel cost: Gas price

Like coal prices, gas prices are modelled with as much granularity as possible but come with a little more complexity due to differences in market structure. In deregulated markets with established gas hubs, such as the EU and US, gas prices are based on reported hub prices. Hub pricing is preferred in these circumstances as it reflects gas-on-gas competition, which is widely regarded as the "true market price" for gas.

In liberalised markets without established hub prices, gas prices are determined by market circumstances. For example, gas prices in Japan and Korea are based on LNG import figures, plus regasification costs. LNG import figures are retrieved from national statistics, if available. Trade figures from UN Comtrade are used as a proxy when national data is unavailable. Regasification costs added on top of landed LNG prices, and are based on existing terminal costs, where available, and industrial averages when specific national figures are lacking.

In semi-regulated and regulated markets, gas prices to the power sector are often kept artificially low, distorting market signals by keeping fossil fuel generation prices low, which disadvantages VRE projects. In these cases, we choose to present the fuel switch dynamic under both the regulated and unregulated price scenarios. While the regulated price scenario presents the actual pricing dynamics in current market conditions, the delta between the regulated and unregulated pricing scenarios may provide additional insights on how energy subsidies are distorting the market and hopefully prompt policymakers to eventually removing such fossil fuel subsidies.

Table 5. Gas price methodology

Gas price methodology	Country	Data source	Detaied methodology
Gas hub pricing	EU-27	ICE (TTF)	Gas prices are based on TTF one-month forward contracts.
	UK	ICE (TTF)	Gas prices are based on TTF one-month forward contracts. Although a national pricing hub exists (NBP), we have aligned with TTF figures due to high tracking of national pricing hubs with TTF.
	USA	EIA	Gas prices are based on spot Henry Hub prices.
Domestic pricing dynamics	China	TransitionZero	Gas prices are based on an average of regulated regional city-gate prices and LNG import costs.
	Vietnam	TransitionZero	Gas prices to the power sector in Vietnam are pegged to HSFO.
	Philippines	TransitionZero	Gas prices to the power sector in the Philippines are pegged to HSFO.

Gas price methodology	Country	Data source	Detaied methodology
LNG import based pricing	Japan	UN Comtrade	Gas prices are based on the costs of landed LNG costs, as reported by import statistics provided by UN Comtrade. Regasification costs are assumed based on the industrial average.
	South Korea	EPSIS, KPX	Gas prices are based on the costs of LNG to the power sector, as reported by EPSIS. Regasification costs are assumed based on the industrial average.
	India	TransitionZero	Gas prices are based on the average of re-gional gas prices. Gas prices in each region are assumed based on their mix of domestic gas, domestic deepwater gas and LNG imports.
Regulated vs unregulated pricing	Indonesia	Regulated: PLN, ESDM regulation	Historical regulated gas prices are based on reported pricing by PLN. Current regulated gas prices are retrieved from government regulations and decrees.
		Unregulated: UN Comtrade	Unregulated gas prices are retrieved from export statistics, based on trade data released by UN Comtrade.

Source: TransitionZero

Carbon cost

Carbon pricing is one of the most common and cost-effective climate policy instruments that governments can use as part of their broader climate strategy. Carbon pricing instruments intend to internalise the externalities associated with carbon emissions, providing a price signal to incentivise low-carbon alternatives. When designed properly, carbon pricing instruments may also facilitate capital flows into low-carbon investments, alleviate distributional impacts of carbon prices and support a sustainable and just transition.

Carbon pricing instruments can be structured either in the form of a carbon tax or an emissions trading scheme (ETS). In the case of a carbon tax, the government mandates a price on stated greenhouse gas emissions and lets market forces determine the quantity of emissions reductions for that price level. Conversely, for an ETS, the government sets the volume of emissions reductions, allowing market forces to determine the appropriate price. In certain jurisdictions, a carbon tax may set the floor or ceiling price of an ETS. Overall, the variance in carbon prices for a certain market is influenced by the type of carbon pricing instrument implemented. Carbon tax instruments tend to see more stable prices, while ETS tend to see large fluctuations in prices. For a more in-depth discussion of the various carbon pricing instruments, please refer to the State and Trends of Carbon Pricing 2021 report by the World Bank.

Due to differences in carbon pricing instruments implemented globally, carbon pricing inputs are modelled based on national circumstances. Table 6 below provides a summary of the assumptions and the data sources used to retrieve carbon prices for each of the modelled countries. For example, carbon prices for the EU come from the EU ETS, while carbon prices for Korea are pulled from the national exchange.

Table 6. Carbon price methodology

Carbon price methodology	Country	Data source	Detaied methodology
ETS	EU-27	EEX	Carbon prices are based on reported prices from the EU-ETS.
	UK	EEX/ICE	Historical carbon prices (pre-2021) are based on reported prices from the EU-ETS. Starting from June 2021, carbon prices are based on reported prices of UK's carbon instrument, UKA.
	China	SEEE	Carbon prices are based on reported CEA prices from the Shanghai Environment and Energy Exchange (SEEE).
	South Korea	KRX	Carbon prices are based on reported prices of KAU.
Carbon tax	Japan	Ministry of Environment, Japan	Carbon prices based Japan's carbon tax of JPY 289/tCO2.

Source: TransitionZero

Note: Countires not included in this table currently do not have a carbon price mechanism implemented.

VRE LCOE

Unlike fossil plants, we have assumed the full costs for VRE projects. This aligns with our intention to estimate the costs associated with shutting down a fossil plant and replacing it with a new-build VRE plant.

The LCOE estimates for VRE are based on country-level estimates. We use IRENA figures where available. Where IRENA figures are unavailable, the VRE LCOE estimates are based on market prices for existing projects. Market prices consider both power purchase agreement (PPA) prices and feed-in-tariff (FIT) prices. Additional renewable energy support schemes that indirectly reduce the cost of renewable energy, such as the Renewable Energy Certificate (REC) scheme and tax breaks, are not considered in the LCOE estimates. Thus, we believe our VRE LCOE estimates tend to align with more conservative estimates.

Table 7. VRE + storage price methodology

VRE price methodology	Country	Data source	Detaied methodology
National cost estimates	EU-27	IRENA	VRE cost estimates drawn from national level estimates from IRENA, where data is unavailable, scaling is applied based on neighbouring countries.
	UK	IRENA	VRE cost estimates drawn from national level estimates.
	USA	EIA	VRE cost estimates drawn from national level estimates.
	China	IRENA	VRE cost estimates drawn from national level estimates.
	Japan	IRENA	VRE cost estimates drawn from national level estimates.
	South Korea	IRENA	VRE cost estimates drawn from national level estimates.
	India	IRENA	VRE cost estimates drawn from national level estimates.
Based on pre-vailing feed-in-tariffs (FITs)/ regulation	Vietnam	EVN	VRE cost estimates are based on prices offered by FITs.
	Indonesia	ESDM	VRE cost estimates are based on prices offered by FITs.
LNG import based pricing	Philippines	DOE	VRE cost estimates are based on prices offered by commercial VRE PPAs.

Source: TransitionZero

Battery storage

The battery storage module is based on a generic lithium-ion battery storage cost model, with scaling factors applied to account for country-level variances. We have explicitly modelled two sources of country-level variation, one from the cost perspective and the other from the VRE resource perspective. Battery storage costs vary by country due to domestic value chains, the relative maturity, or immaturity, of the markets, and other socio-economic factors. The second source of variation lies in the differences in resource potential, i.e. capacity factor of VRE, in various geographies. Pairing VRE with battery storage will see the battery pack take on the capacity factor of the VRE resource.

Forward-looking analysis

In our forward-looking analysis, we have primarily focused on the impact of volatile commodity prices (including coal, gas and carbon prices) and the deflationary pressures of VRE+storage applications, while holding other parameters steady. In this sub-section, we will detail our methodology for forward-looking analysis.

Forward-looking coal prices

Future coal prices are modelled primarily based on future contracts. Where nation-specific futures contracts exist, such as in the case of EU and China, monthly coal futures prices are based on the prevailing price for the future contracts due for delivery in that specified month.

Where nation-specific coal price indices are non-existent, we estimate the future coal price based on a mix of international coal pricing hubs, with actively traded futures contracts. This includes Newcastle coal futures (Australia), ICE FOB Indonesia coal futures and ICE Richard Bay coal futures (South Africa). Country variation is represented by varying the share of each international coal hub, based on historical trade exposure.

In cases such as Indonesia and the US, where the power sector mostly consumes domestic coal and there is a lack of actively traded futures contracts which enable price discovery, we consider each country on a case-by-case basis, with the intention to provide accurate representations of the forward-looking coal price in each country.

Table 8. Coal futures price methodology

Coal price methodology	Country	Data source	Detaied methodology
Nation-specific coal pricing indices	EU-27	ICE (API 2)	Coal prices are based on futures contracts based off API 2.
	UK	ICE (API 2)	Coal prices are based on futures contracts based off API 2.
	China	Zhengzhou commodity exchange	Coal prices are based on futures contracts for China thermal coal.
International coal pricing indices	Japan, South Korea, Indonesia, Philippines, Vietnam	globalCOAL, ICE	Coal prices are based on futures contracts on a variety of international coal trading hubs, with actively traded futures markets. This includes globalCOAL New-castle coal futures (Australia), ICE FOB Indonesia coal futures and ICE Richard Bay coal futures (South Africa). Country variation is represented by varying the share of each international coal hub, based on historical trade exposure.

Coal price methodology	Country	Data source	Detaied methodology
Imports-based	USA	EIA	Given a lack of actively traded US coal futures contracts, we have held the regional coal prices steady. Coal prices for the US are updated on a weekly basis, and the most recent data point will be held constant as forecast.
	Indonesia	Regulated price: ESDM regulation Unregulated price: globalCOAL, ICE	The regulated coal price to power is adjusted every year, based on a discount on prevailing international coal prices, as represented by a basket of international coal indices. We assume regulated coal prices in the power sector to be constantly at a discount to unregulated coal prices. The unregulated coal price is estimated based on our international coal pricing methodology described above.
	India	India regulation, globalCOAL, ICE	Future coal prices are calculated based on a mix of international coal import-based pricing and regulated pricing. Regulated coal prices are assumed to hold steady. Imported coal prices are modelled based on our international coal pricing methodology described above.

Source: TransitionZero

Forward-looking gas prices

Where established gas hubs with an actively traded financial futures market exist, such as in the EU (TTF) and US (Henry Hub), gas prices are based on the prevailing price for the future contracts due for delivery in that specified month.

In markets without futures markets, forward-looking gas prices are modelled primarily based on existing gas pricing structures in the country. For example, gas prices in the Philippines and Vietnam are pegged to HSFO prices. This pricing mechanism is assumed to hold in our analysis. We will then supplement our analysis with futures for HSFO, which has actively traded futures instruments.

In markets where a mix of regulated and unregulated gas prices exist, such as in China and India, future gas prices are calculated based on a mix of LNG import-based pricing and regulated pricing. Due to the relative permanence of government policy, we have assumed that regulated gas prices hold steady, while unregulated gas prices are allowed to fluctuate. Unregulated gas prices are modelled based on our in-house LNG import-based pricing methodology, which is described in detail below.

In most of Asia, spot LNG prices, such as the Japan-Korea-Marker (JKM), do not drive LNG prices in the power sector. Instead, most LNG-based power plants procure the bulk of their gas requirements in the form of long-term oil-indexed LNG contracts. In view of this, we modelled future LNG/gas prices for power plants based on the following factors:

- Share of term LNG vs spot LNG
- Slope of oil-indexed (Brent) term LNG contracts
- Constant for oil-indexed term LNG contracts

Brent futures prices are based on the prevailing price of the financial futures contract on Brent due for delivery on the specified month. Spot LNG prices are proxied by the JKM retrieved from CME. Regasification costs are added to the landed LNG costs. Country variation is built in through variation in the factors listed above.

Table 9. Gas futures price methodology

Gas price methodology	Country	Data source	Detaied methodology
Gas hub pricing	EU-27	ICE	Future prices are based on monthly futures contracts based on TTF.
	UK	ICE	Future prices are based on monthly futures contracts based on TTF. Although a national pricing hub exists (NBP), we have aligned with TTF figures due to the high tracking of national pricing hubs with TTF.
	USA	CME	Gas prices are based on futures contracts based on Henry Hub.
Domestic pricing dynamics	Vietnam	TransitionZero, ICE	Future prices are based on monthly futures contracts for HSFO.
	Philippines	TransitionZero, ICE	Future prices are based on monthly futures contracts for HSFO.
LNG import-based pricing	Japan, South Korea	TransitionZero	Gas prices are based on the assumptions of costs of LNG imports and are driven by the following factors: • Share of term LNG vs spot LNG • Slope of oil-indexed term LNG contracts • Constant for term LNG contracts Regasification costs are assumed based on the industrial average.

Gas price methodology	Country	Data source	Detaied methodology
Regulated pricing and LNG import-based pricing	India	TransitionZero	Future gas prices are calculated based on a mix of LNG import-based pricing and regulated pricing. Regulated gas prices for domestic production and deepwater domestic gas are assumed to stay constant, while LNG import prices are calculated based on the LNG import-based pricing methodology.
	China	TransitionZero	Future gas prices are calculated based on a mix of LNG import-based pricing and regulated pricing. Regulated city-gate prices are assumed to hold steady, with variations stemming from LNG import prices, modelled using our in-house methodology described below.
Regulated vs unregulated pricing	Indonesia	Regulated: PLN, ESDM regulation Unregulated: UN Comtrade	Regulated gas prices are capped at US$6/MMBtu, delivered to the plant gate, based on government regulations and decrees. Unregulated gas prices are estimated based on our in-house methodology.

Source: TransitionZero

Forward-looking carbon prices

Similar to forward-looking coal prices, markets with an actively traded financial futures market on carbon price instruments, such as the EU (EUA), UK (UKA) and Korea (KRX), have future carbon prices based on the underlying financial futures contract. In markets that rely on ETS systems but lack an underlying financial futures market, such as China, future carbon prices are estimated based on analyst opinions on forward-looking carbon prices.

Countries with a carbon tax will see their carbon tax price level holding steady until a policy change is announced.

Table 10. Carbon futures price methodology

Carbon price methodology	Country	Data source	Detaied methodology
ETS	EU-27	EEX	Carbon prices are based on EUA futures prices.
	UK	ICE	Carbon prices are based on UKA futures prices.
	China	TransitionZero	Carbon prices are based on analyst forecast prices for China's ETS.
	South Korea	KRX	Carbon prices are based on KAU futures prices.

Carbon price methodology	Country	Data source	Detaied methodology
Carbon tax	Japan	Ministry of Environment, Japan	Carbon price of JPY289/tCO2 expected to hold till policy change is announced.
Upcoming carbon price	Indonesia	Ministry of Finance, Indonesia	Indonesia to implement carbon price from July 2022.

Source: TransitionZero

Note: Countires not included in this table currently do not have any stated plans to implement a carbon price

Forward-looking VRE + storage prices

The past decade has seen a rapid decline in the cost of VRE+storage applications driven by an agglomeration of factors, including economies of scale, technological breakthroughs, favourable policies, among others, which have contributed to steep learning curves. This trend is set to continue. As such, we have accounted for the deflationary pressures on VRE+storage projects in our forward-looking analysis by applying a discount to existing LCOE estimates, based on historical learning rates.

04 Limitations

We acknowledge that the current iteration of the C3PI faces several shortcomings. These shortcomings are detailed below.

1. **Short-term.** One of the key shortcomings of using C3PI to inform long-term decision-making is its short-term nature. While the tool helps track short-term price fluctuations, its findings may not translate well into long-term decision-making with decade-long impacts, particularly for new-build gas plants or grid infrastructure. As such, we envision this tool to be part of a suite of other financial and climate tools, which complements other long-term models by layering it with a short-term perspective. We view the C3PI as an essential tool that bridges the gap between short-term market movements and long-term strategic thinking.
2. **National aggregation.** Another apparent weakness of C3PI stems from its national-level data aggregation. While national-level analysis provides high-level conclusions that can facilitate policy discussions, it loses vital regional dynamics and sensitivities. While we recognise the risks of aggregation, we view this primarily as a challenge in balancing detailed regional analysis and broad national trends. We view C3PI as a high-level screening tool and as a primer for more detailed asset-level analysis, which can be provided by our Coal Asset Transition (CAT) tool, due to be released in Summer 2022.
3. **Dispatchable renewables.** Battery storage is not a like-for-like replacement for coal. As mentioned earlier, battery storage can serve multiple purposes. When coupled with VRE generation, battery storage can help to manage intermittency and potentially improve plant economics. In fact, replacing coal with VRE coupled with battery storage may add value to the grid by providing additional flexibility. However, the ability of battery systems to add value to the grid needs to be balanced with the design parameters, particularly in terms of power rating and duration.

05 Use cases

We believe that C3PI is useful to various stakeholders, including investors, policymakers, and civil society, among others. In this section, we highlight how we hope C3PI will be used.

Use cases for policymakers

1. **Provide ongoing evaluation of the cost-competitiveness of VRE+storage against fossil fuel generation**

   C3PI provides an ongoing, near real-time evaluation of the cost-competitiveness of VRE+storage applications versus fossil fuel generation. This sidesteps potential criticisms of outdated analysis, particularly during times of volatile commodity prices.

   In fact, with C3PI actively tracking commodity price swings, the results will also help to bring to the fore the reality of volatile fossil fuel prices, and the associated risks, particularly surrounding financial viability. This could help raise the attractiveness of VRE+storage applications, given its favourable contributions to energy security.

2. **Promote policy discussion on coal retirement and leapfrogging gas**

   The results of C3PI will hopefully be useful in showcasing the relative low-cost opportunities presented by a coal-to-clean switch, and thus prompt policy discussions surrounding coal retirement and a potential leapfrogging of gas.

3. **Evaluate the effectiveness of carbon pricing instruments**

   With the results of C3PI being represented on a $/tCO2 basis, our coal-to-gas and coal-to-clean estimates are clear proxies of carbon price levels that can trigger fuel switches to gas and renewables, respectively. This should be useful for countries with a carbon price to evaluate the effectiveness of their policy instrument to trigger fuell switching in the power sector.

   In countries without an existing carbon price, our results will present a good starting point for discussions on the introduction of a carbon price.

4. **Inform policy decisions on energy subsidies**

   In some markets, price regulation of fossil fuels has kept coal and gas prices artificially low, eroding the cost-competitiveness of zero-carbon electricity. Such policies are often introduced to ensure energy affordability, particularly in developing economies. However, the impacts of fossil fuel subsidies may do more harm than good. Fossil-fuel subsidies hamper the market's ability to tap into deflationary trends of VRE+storage and benefit from their positive impact on electricity prices. Moreover, these fossil fuel subsidies are also a drain on the national budget, which pulls public spending away from other priority sectors such as healthcare and education.

C3PI displays a regulated versus unregulated view in markets where fossil fuel subsidies distort the market. This provides a clear visualisation of how regulation has introduced perverse incentives that discriminates against zero-carbon generation, and can hopefully help to further policy discussion on the phase-out of fossil fuel subsidies.

Use cases for investors

1. **Highlight the increasing importance of short-term price dynamics due to climate risk**

   Short term price volatility is seldom built into long term project finance models apart from sensitivity analysis, which is often conducted as an afterthought. The general understanding within the financial community is that these fluctuations are noise in long-term projections, and will eventually cancel each other out.

   However, there is more evidence that climate change is shifting the balance of risk. Climate change can impact LNG prices in two ways. The first is from climate transition risk. Banks are increasingly wary of investments in oil and gas projects. The world we are stepping into will likely see tightly balanced LNG and coal markets, that are more prone to price swings in response to unexpected demand and supply shocks.

   The second is from the physical impacts on energy infrastructure. Due to climate change, physical infrastructure, such as upstream oil and gas projects, and downstream power plants, may be more susceptible to unplanned shutdowns due to extreme weather events. These events may manifest as either supply or demand shocks to fossil fuel markets, triggering volatile commodity prices. So it seems clear that going forward, fossil fuel prices are only going to be more unpredictable and volatile. This has a clear financial impact on current and future projects, which has to be appropriately accounted for at the project finance stage.

   By providing an ongoing, near real-time tracking of volatile commodity prices and their impacts on the cost-competitiveness of fossil fuel generation, we hope that C3PI will inform investor decision-making on how short-term fossil fuel price volatility is impacting the financial bottom line for new and existing fossil fuel generation.

2. Establish an economic license to operate for VRE+storage applications

We envision C3PI to be an important tool to correct investor misconceptions about the cost of VRE+storage projects. In particular, our forward-looking analysis presents near real-time actionable insights that are can be used to provide a strong business case for zero-carbon electricity and help drive investments into VRE+storage applications.

06 Conclusion

We developed C3PI to fill a critical gap in short-run energy analytics. Despite increasing volatility in commodity prices, there is a current lack of tools in the market that actively track the impact of fossil fuel price volatility on the cost-competitiveness of fossil fuels vis-a-vis renewable energy and battery storage. In the absence of data-backed analysis, long-term decisions on fossil plants may be based on unrealistic assumptions, resulting in an inflated financial valuation of these assets that are increasingly exposed to extreme and more frequent fuel price volatility. C3PI captures the short-run cost-competitiveness of coal, gas, and renewables amid turbulent global energy markets, and offers fresh insights on the cost-competitiveness of the economics of VRE plus battery storage applications. Hopefully, the C3PI will help uncover short-run pricing dynamics to inform long-term decision-making. We also envision C3PI as a useful tool for the investment community, policymakers, media practitioners, academia, civil society and the general public. We hope that C3PI can be used effectively by the myriad of stakeholders to advance the discussion of leapfrogging gas to mature renewables coupled with battery storage as a replacement for coal assets.

07 Resources

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