Breakthrough Energy

Emerging Climate Technology Framework

Methodology for impact analytics

January 2023

Introduction

There is growing interest among policy makers, companies and financial institutions in investing in the emerging climate technologies (ECTs) that are critical for a net-zero future, in the hope of reducing their cost and accelerating their deployment globally. Yet there is not currently a robust analytical framework for assessing the potential climate impact of these investments The Emerging Climate Technology Framework (ECTF) fills this gap with the introduction of two forward-looking metric: 1) reductions in cost compared to the incumbent fossil technology, which we refer to as Green Premium Reduction (GPR); and 2) potential future greenhouse gas emissions avoided which we refer to as Catalyzed Emissions Reductions (CatERs). This document outlines a methodology for quantifying both. The ECTF was developed by Breakthrough Energy (BE) and Rhodium Group as a tool for evaluating investments made through BE's Catalyst program, but has utility for other investors as well as policymakers interested in accelerating ECT deployment.

Impact Metric	Definition
Green Premium Reduction (GPR)	Forward-looking decrease in price premium at a specific point in time of an Emerging Climate Technology (ECT) over a fossil incumbent (or target price, depending on the technology) brought on by investments to catalyze ECT deployment.[1]
Catalyzed Emissions Reduction (CatER)	Potential future emissions reduced due to catalytic investments that accelerate additional global ECT deployment.

Table 1: Impact Metric Definitions

Overview of the Emerging Climate Technology Framework Model

WHY DO WE NEED SUCH A FRAMEWORK

Nearly 50% of emissions reductions needed to achieve global Net Zero by 2050 will be driven by emerging climate technologies (ECTs)[2], but they often lack the funding to deploy at scale and speed. Policymakers, companies and financial institutions can accelerate deployment of ECTs by providing catalytic capital and/or executing offtake agreements at a premium, but to date these entities have lacked an analytical framework for assessing the potential climate benefit of such investments. Breakthrough Energy and Rhodium Group developed the Emerging Climate Technology Framework (ECTF) to fill this gap.

---

[1] https://www.gatesnotes.com/Energy/Introducing-the-Green-Premiums
[2] Estimates for emissions reductions needed from new technologies range from ~30% in IPCC's P4 pathway to nearly 50% in IEA's Net Zero by 2050: A Roadmap for the Global Energy Sector.

WHAT IS THE ECTF MODEL?

Concept: The ECTF Model defines and implements a technology-agnostic methodology to quantify the expected impact of early-stage investments made in ECTs. This model relies on the concept of "catalytic capital," which is defined as: investment capital that is patient and accepts disproportionate risk and/or concessional returns relative to a conventional investment to generate positive impact and enable third-party investment that otherwise would not be possible.[3]

The ECTF is anchored in the historical evidence of how early investment in solar technologies accelerated cost reductions and scaled deployment worldwide. Figure 1 illustrates how even earlier investment in solar PV would have brought costs down significantly – a $5 billion investment just 5 years earlier would have brough costs down by nearly half in just 5 years. Those cost declines lead to accelerated market adoption of solar, essentially shifting the deployment curve for solar PV forward by five years (Figure 2).

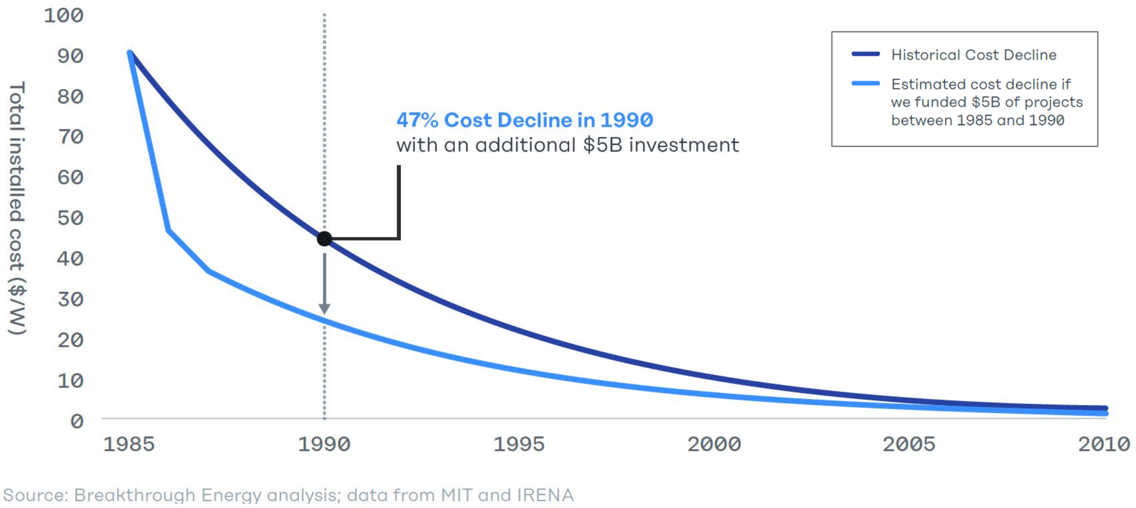

Figure 1: Solar Example: If we had invested $5B in 1985, solar costs would have come down sooner. As a result of these cost declines, solar would have been adopted more quickly into the market.

---

[3] https://www.macfound.org/programs/catalytic-capital-consortium/

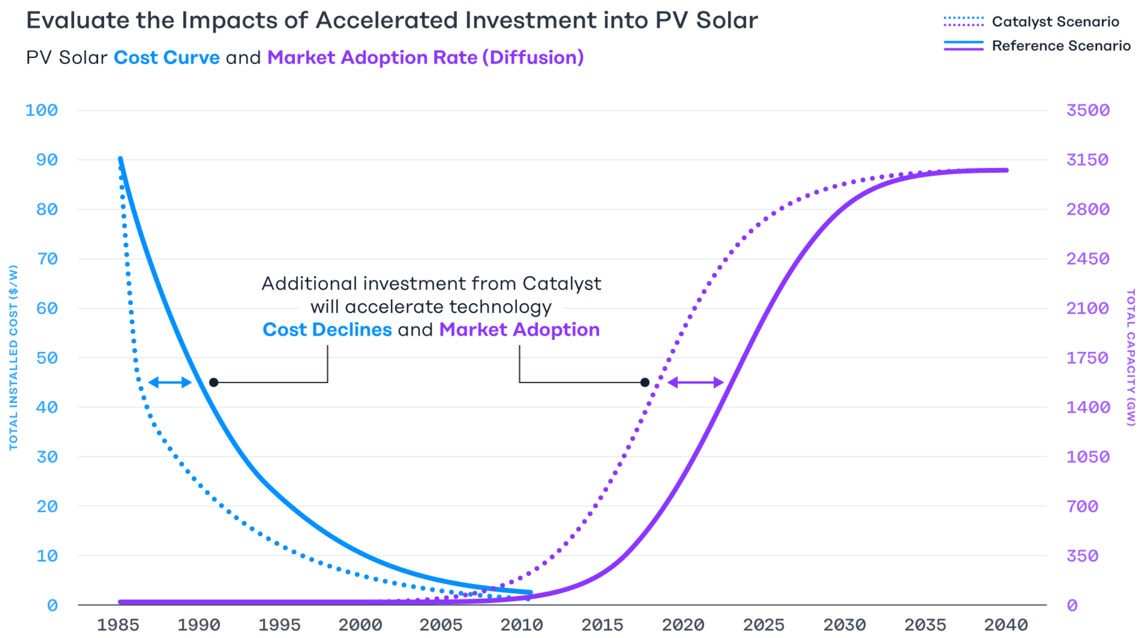

Figure 2: Solar Example of how additional investment accelerates technology cost declines and market adoption. As a result of cost declines, solar would have been adopted more quickly into the market.

Following the solar investment example, to quantify the impacts of catalytic capital in emerging climate technologies, the ECTF model assesses two cases: a baseline case in which current market and policy trends are assumed to continue, and a catalyzed case in which there is an injection of catalytic capital of a specified size in the near term (within ~5 years of present). In both cases, ECTs are expected to be adopted over time, but in the catalyzed case, adoption occurs more quickly. By comparing the difference between the baseline and catalyzed case, it is possible to quantify the additional impact of the catalytic capital over the long term.

Types of capital: The ECTF model accounts for multiple types of catalytic capital. By evaluating the full catalytic capital stack, it is possible to attribute the modeled impact metrics to specific investments, thus giving recognition to specific investors providing catalytic capital for their contributions.

Scenarios: The ECTF model provides assessments of projected impact based on current market conditions and assumptions around the future. Because of the inherent uncertainty of these assumptions, the ECTF model provides a range of scenarios accounting for energy market dynamics and technology cost paths. The model will be updated annually to capture evolving policy and market dynamics and account for updates related to the costs and learning rates for specific technology pathways under consideration.

Technology Scope: The ECTF model is designed to quantify the impact of early-stage investments into technologies currently meeting the conditions for levels 5 through 10 of the Technology Readiness Level (TRL) scale defined by the IEA. Level 5 is a large prototype in which components have been proven in the conditions in which they will be deployed, while level 10 is integration at scale in which the solution is commercially available but needs further integration efforts into broader systems to scale predictably.[4] The ECTF model was initially developed for four emerging climate technologies – Sustainable Aviation Fuels (SAF), Direct Air Capture (DAC), Clean Hydrogen, and Long Duration Energy Storage (LDES) – and will be updated in future iterations to include additional technologies.

HOW DOES THE ECTF MODEL DIFFER FROM OTHER CLIMATE IMPACT MODELING?

ECTF shares both important commonalities and key differences with existing climate impact modeling methods and tools. The ECTF approach is unique in that it: (a) is forward-looking (as opposed to present value or historical accounting); (b) assesses the impacts of catalytic investments in ECTs; (c) measures the climate-specific impact (as opposed to the financial impacts of catalytic investments); and (d) measures impact at a technology level (but not at a specific company or project level).

TREATMENT OF UNCERTAINTY IN THE ECTF MODEL AND LIMITATIONS OF THE APPROACH

Accounting for the impacts investments have today, or may have in the future, is an inherently uncertain exercise. All estimates – whether backward or forward-looking - require modeling and analysis based on assumptions about what would have happened absent the specific climate or investment action.

In this respect, the community of climate impact practitioners has a long-established practice of dealing with uncertainty. The ECTF leverages many of the same approaches to uncertainty as other climate impact metric models. To address a range the uncertainties, the ECTF uses a scenario-based approach to capture a range of potential future outcomes (the “Summary of Assumptions” section of this document describes the scenario approach for the ECTF model).

Like other impact metrics, the ECTF model is sensitive to assumptions. There is not broad consensus on specific inputs, such as the share of catalytic investment that can be translated into market learning. The values used for inputs are based on expert judgement and empirical data where possible, but in many cases, are still uncertain. To deal with this limitation, the ECTF uses a scenario-based approach to incorporate uncertainty in technology learning rates and other key parameters.

Finally, it is also difficult to estimate the likelihood of success for a specific ECT pathway. The ECTF model assumes the technologies receiving catalytic investment will be successfully scaled at some point in the future (given they have reached at least IEA TRL 5), but there is an inherent risk of technology failure that is impossible to estimate, and thus not accounted for in the model.

[4] https://www.iea.org/reports/clean-energy-innovation/innovation-needs-in-the-sustainable-development-scenario

The Emerging Climate Technology Framework Model Implementation

HOW THE ECTF MODEL WAS DEVELOPED

The ECTF Model development was led by Breakthrough Energy, in partnership with the Rhodium Group and the Carbon Disclosure Project. The original ECT Framework[5], published in 2021, has been further adapted and refined based on inputs from multiple rounds of broad stakeholder engagement. These stakeholders include leaders in corporate sustainability, opinion leaders, academics and topic experts. Rhodium Group, in partnership with Breakthrough Energy, has implemented a new baselining approach based on Rhodium's Global Energy Model (RHG-GEM). Additionally, some specific ECTF methods (such as the calculation of effective catalytic capital) have been adjusted relative to the original BE / CDP methodology. The methodology that follows accurately describes the implementation of the BE ECTF Model as of March 2023.

MODEL OVERVIEW

The ECTF model ("the model" from here forward) estimates the key impact metrics in three overall steps, each building on the last. The first step is to construct baseline deployment curves (i.e., installed capacity as a function of time) for each ECT under reasonably expected policy and market conditions through the end of the century ("baseline case"). Second, the model estimates the impact of catalytic investments on the ECT adoption curve, specifically estimating the acceleration of adoption driven by the specific investment ("catalyzed case"). Third, leveraging the baseline and catalyzed adoption cases, the model calculates the catalytic metrics to assess the green premium reduction and catalyzed emissions reductions and allocates them to specific investments / investors. A summary diagram of the basic model construction is below:

[5] https://www.cdp.net/en/campaigns/emerging-climate-technology-initiative

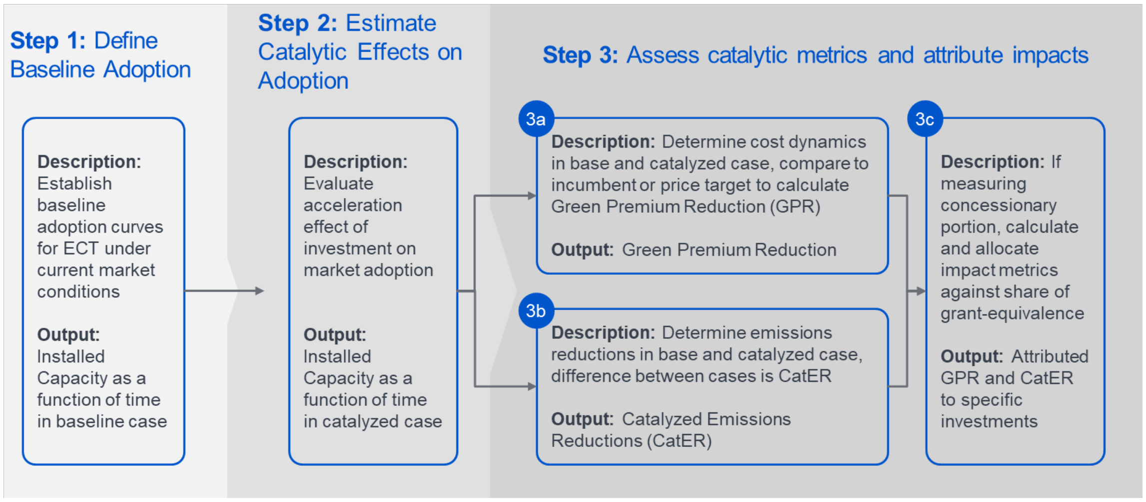

Figure 3: Summary of ECTF Model Methodology including steps, descriptions, and outputs. The labeled steps tie to the following methodology sections.

TECHNOLOGY CHARACTERIZATION

The ECTF currently models the deployment of four emerging climate technologies: Sustainable Aviation Fuel (SAF), Direct Air Capture (DAC), Clean Hydrogen, and Long Duration Energy Storage (LDES). Each technology competes in the marketplace based on a range of input assumptions about the expected cost and performance. Below we outline the technology pathways – specific approaches to ECTs that differ in key attributes such as costs, emission profiles, or incumbent technologies -- that are currently in scope.

Technology	Pathways	Definition
Sustainable Aviation Fuel (SAF)	Power to Liquid, Alcohol to Jet, Biomass Gasification, Hydrotreated Esters and Fatty Acids	SAFs are jet fuels derived from sustainable sources such as biological feedstock and renewable energy. Currently, SAFs can be used in any jet engine if they are blended (max 50%) with kerosene (jet fuel A1). There are 2 types of SAF—biofuels made from biological feedstocks (e.g., vegetable oils, agricultural residue waste, municipal solid waste) and synthetic fuel made from artificial chemical synthesis using renewable electricity, captured carbon, and water. There are seven approved pathways to produce SAF today, three of which have higher relative maturity and are in-scope: Hydrotreated esters and fatty acids (HEFA), Biomass Gasification (GFT), and Alcohol-to-Jet (ATJ) to produce biofuels. The nascent Power-to-Liquid (PtL) pathway used to produce synfuels is also in scope.
Direct Air Capture (DAC)	Solid Sorbent	Direct air capture (DAC) is one of many negative emission technologies (NETs) that captures CO2 from ambient air. There are two leading DAC technologies available today, aqueous

		solution and solid sorbent, with OEMs seeking to build their first large-scale plants. The solid sorbent pathway is in-scope.
Clean Hydrogen	Renewables-Based Electrolysis, Methane pyrolysis, Biomass/municipal waste gasification, Fossil fuel-based with carbon capture	Electrolytic hydrogen (H2) is produced via electrolysis of water to create H2 and O2 using electricity. Three main pathways for green H2: Alkaline Water Electrolyzer (AWE), Proton Exchange Membrane (PEM), and Solid Oxide Electrolyzer (SOE). H2 can also be produced via methane pyrolysis or biomass gasification. The former creates hydrogen and solid carbon through the thermal decomposition of methane or bio-methane. The later converts biomass or municipal waste to hydrogen. When coupled with carbon capture and storage, the net carbon emissions of biomass gasification can become negative. Lastly, H2 from fossil fuel equipped with carbon capture can yield a production emissions intensity substantially lower than today's uncontrolled fossil production. Since significant uncertainty remains regarding the future of H2 production, this pathway is in scope.
Long Duration Energy Storage (LDES)	Mechanical (gravitational, compressed/liquid air energy storage, modular pumped hydro) Electrochemical batteries (redox flow batteries, aqueous solution, metal-air) Thermal (refractory, molten salts) Chemical (clean hydrogen production, storage, and re-electrification)	Long duration energy storage (LDES) is key to addressing intermittency of renewable energy generation due to its ability to store & discharge electricity for 10+ hours at a time. There is a broad landscape of LDES technologies, which can be bucketed into four major classifications: mechanical, thermal, chemical, and electro chemical. All pathways are similar in terms of market adoption likelihood, so are modeled as a single combined pathway.

Table 2: Summary of initial in-scope ECTs for BE ECTF Model

STEPWISE ESTIMATION PROCEDURE

The BE ECTF model methodology described in the following section is used to calculate ECTF impact metrics as defined above. This methodology is specific to the BE ECTF model, and is covered in five sections below:

1. Step 1: Define Baseline Adoption
2. Step 2: Estimate Catalytic Effects on Adoption
3. Step 3a: Assess Green Premium Reduction
4. Step 3b: Assess Catalyzed Emissions Reduction
5. Step 3c: Attribute Impacts to Investors and Investments

STEP 1: DEFINE BASELINE ADOPTION

To calculate catalyzed emission reductions and reductions in the green premium, the model must assess the difference in emission reductions achieved by a given technology under both a baseline scenario and in the presence of catalytic investment. In both the baseline and catalyzed cases, the total size of the market for the given technology is held constant, but in the catalyzed case that market size is reached sooner. The main challenge in this approach is ensuring that the baseline definition is consistent across technologies and ensuring that the technology cost and performance assumptions used to create the baseline are consistent with that being used to calculate the catalyzed case. No currently available baseline projections meet these criteria.

This is best illustrated by looking at the current International Energy Agency (IEA) World Energy Outlook (WEO)[6] and Energy Technology Perspective (ETP)[7], the most commonly used global technology baselines. Both rely on two extreme scenarios: 1) the Stated Policies Scenario (SPS) which includes those policies already announced by governments but nothing more; and 2) the Sustainable Development Scenario (SDS) assumes governments put in place additional policies sufficient to reduce global emissions enough to limit global temperature increases to less than 2°C. Neither scenario works well as a baseline for the ECTF. In the SPS scenario, the total market size for many of the emerging climate technologies will be zero or close to zero. In the SDS, large scale deployment of DAC, SAF, Clean H2 and LDES is achieved, assuming that the early-stage investment Catalyst is anticipating has already occurred.

To address this issue, the ECTF requires custom baseline scenarios to ensure that the technology cost and performance assumptions are consistent across baseline and catalyzed scenarios. To do so, Rhodium Group developed baseline scenarios using RHG-GEM, an enhanced version of the US Energy Information Administration's World Energy Projection System (WEPS)[8]. WEPS is a fully open-source model used by the IEA to produce the International Energy Outlook (IEO)[9]. A more

[6] https://www.iea.org/reports/world-energy-outlook-2021
[7] https://www.iea.org/topics/energy-technology-perspectives
[8] World Energy Projection System
[9] International Energy Outlook

detailed overview of Rhodium's Global Energy Model and 2022 ECTF baselines is available in the Emerging Climate Technology Framework Technical Appendix.

Using RHG-GEM, Rhodium developed global baseline projections for each ECT under an "expected" policy scenario, producing baseline adoption curves for each ECT. This curve represents the installed capacity as a function of time, indexed annually. The baseline is modeled through 2100 so it can be pulled forward in time in the following steps, as capacity beyond 2050 is pulled forward as a result of catalytic investment. While the unit for installed capacity varies by technology, the output through 2050 can be represented by the figure below:

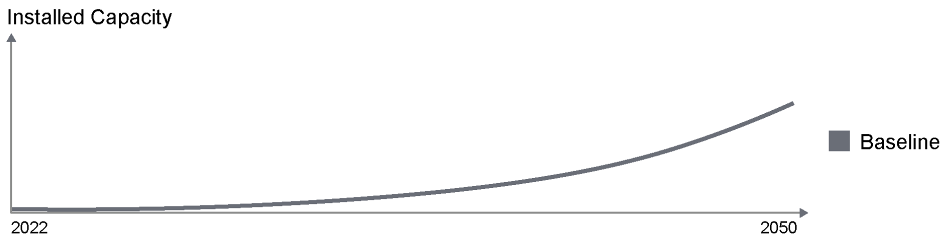

Figure 4: Illustrative baseline adoption curve (installed capacity as a function of time)

STEP 2: ESTIMATE CATALYTIC EFFECTS ON ADOPTION

After the baseline has been defined, the second step in the model estimates the effect of the specific catalytic investment on the baseline adoption curve.

Baseline Curve Shift for Catalytic Investment

Based on the investment scale and timing, and current cost per unit of the ECT, the capacity uplift "bought" by the catalytic capital can be used to accelerate the baseline case, in turn, generating the catalyzed adoption curve. The model uses a simple time-based curve shift. The model first solves for the capacity after investment, then identifies the future point in time at which that cumulative capacity would otherwise have been achieved in the baseline case. That point and all subsequent points on the baseline curve are pulled forward by the same time increment, thus accelerating the adoption curve while maintaining the adoption curve shape in the final catalyzed adoption curve.

This method assumes that any other changes reflected in the baseline adoption curve over the acceleration period will not have a large impact on the catalyzed rate of adoption. This will be validated by comparing the "time-shifted" catalyzed curve against an independently calculated catalyzed adoption curve generated using the same model used to generate the baseline while incorporating the catalytic investment as an input before solving for equilibrium.

Outputs

The output is a catalyzed adoption curve for the specific ECT pathway and catalytic investment amount and timing. This curve represents the installed capacity in the catalyzed case as a function of time, indexed annually. The unit for installed capacity varies by technology. The output is represented by the figure below (relative to the baseline case):

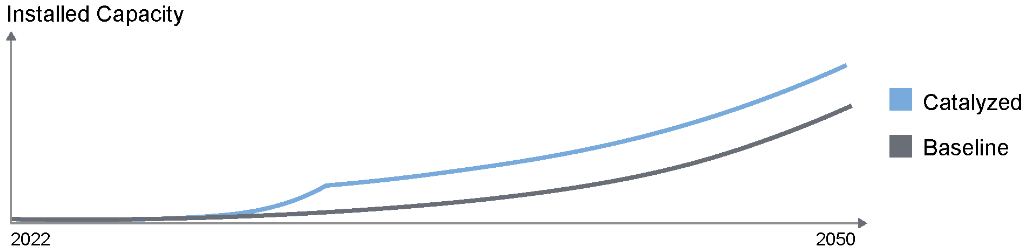

Figure 5: Illustrative catalyzed adoption case compared to baseline case demonstrated accelerated adoption due to catalytic capital

STEP 3A: ASSESS GREEN PREMIUM REDUCTION

Based on the adoption curves for the baseline and catalyzed adoption curve, the green premium reduction for each case can be calculated.

Create Learning Curves

To calculate the green premium, the learning curve must first be determined. The learning curve, in this case, represents unit cost as a function of experience, and is estimated using a generic single factor learning curve, as dictated by Wright's Law (depicted in the equation in figure 9 below). The learning curve implies that scaling up capacity drives costs down, underscoring the fundamental logic of catalytic capital.

For many ECTs, technology learning rates are difficult to estimate empirically due to the lack of historical deployment experience and data. ECT learning curves are therefore based on the best-available academic research, input from industry experts, and technological maturity. For a detailed overview of learning curve assumptions, see the Emerging Climate Technology Framework Technical Appendix. Learning curves in terms of installed capacity are incorporated in RHG-GEM baseline modeling, driving cost declines as a function of deployment. Once the learning curve in terms of installed capacity is known, the costs can be mapped against the adoption curves from step 2 to translate into a cost curve as a function of time. This is the annualized cost curve. The adoption curve demonstrates a ramp-up over time in installed capacity, and the learning curve demonstrates a decrease in unit cost because of increased production volume; the cost per unit will fall over time due to these combined effects.

Calculate Green Premium Reduction

Using the annualized cost curves, it is possible to calculate the Green Premium Reduction. The first step in defining the GPR is defining the green premium, which is the difference between the cost of the ECT and the cost of the incumbent technology that it will replace. The cost of the incumbent is calculated based on average market costs today, which is based on the assumption that the identity and cost of the incumbent technology does not change because of the ECT investment, and as such, is held constant. In cases where the ECT replaces more than one technology, the cost of the incumbent is defined as the average of the displaced technologies, weighted by their deployment in the baseline case.

In cases where there is no incumbent technology being replaced, such as is the case for DAC, a cost target may be used. The cost goal for DAC could be interpreted as: “The goal for direct air capture is to reduce costs to $100/ton as quickly as possible”. Like other Green Premium Reduction methods, progress towards that goal can be represented as a percent decline.

This methodology is summarized below:

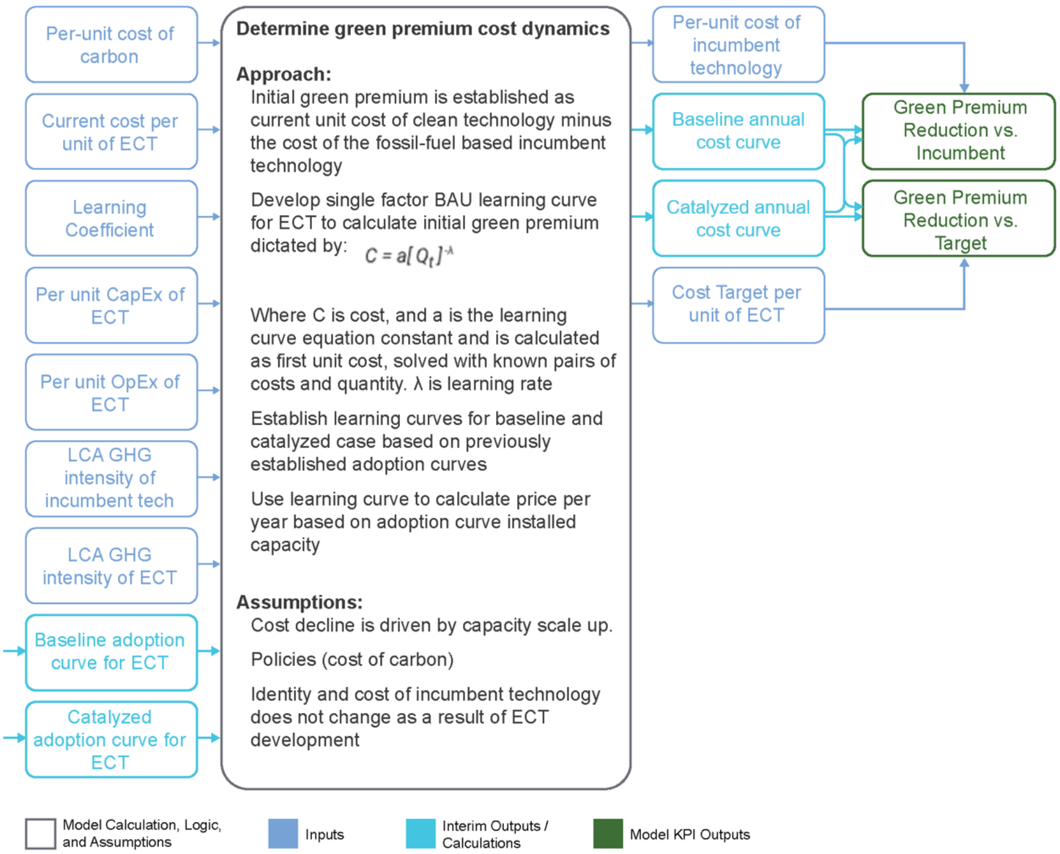

Figure 6: Green premium calculation methodology summary

Outputs

Leveraging the annualized cost curves and incumbent cost or cost target, the GPR is calculated. The difference between the initial green premium and the future state green premium is referred to as the Green Premium Reduction. Both the baseline and catalyzed case will drive Green Premium Reduction, and as such, it is also possible to calculate a Catalyzed Green Premium Reduction, which is the difference in GPR between the baseline and catalyzed case. This metric can be expressed in multiple ways – as either an absolute or percentage reduction compared to either the baseline case or the initial green premium.

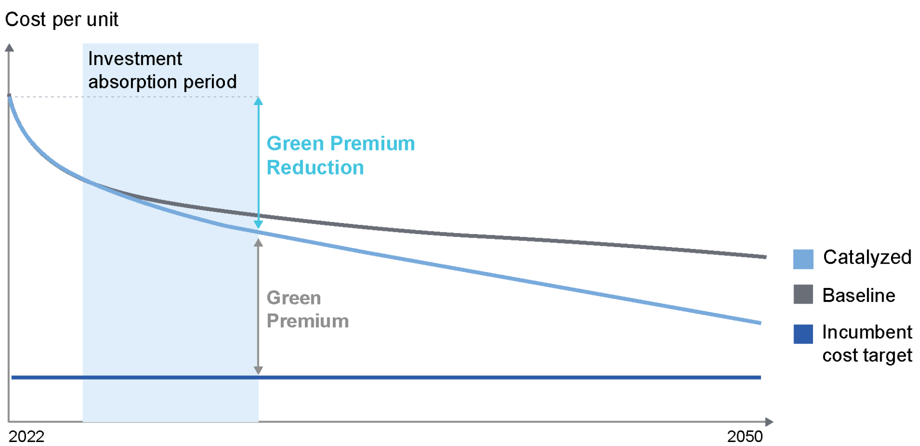

Figure 7: Illustrative green premium and green premium reduction metric calculation approach based on learning curve as a function of time in baseline and catalyzed case. Green premium is measured after the initial increase in investment has been absorbed by the market and fully translated into capacity.

STEP 3B: ASSESS CATALYZED EMISSIONS REDUCTIONS

Based on the adoption curves for the baseline and catalyzed cases, it is possible to estimate the additional future emissions reductions from the ECT driven by the catalytic investment, which is the Catalyzed Emissions Reduction (CatER). The Green Premium Reduction is related, but not required as an input to calculate CatER, but like the GPR calculation, each of the baseline and catalyzed cases use the same methodology to calculate emissions reductions, and the difference between the scenarios is CatER.

Characterize emissions profiles

First, the emission intensities of the incumbent and ECT must be characterized to calculate the abatement factor, which is used to estimate emissions reductions. The abatement factor is defined as the per-unit carbon impact of one unit of ECT, calculated as the emissions of the incumbent technology per functional unit minus the emissions of the ECT per functional unit. Similar to the approach for calculating the GPR, the weighted average emission intensities are used when there is more than one incumbent. The emission intensities for ECTs and their incumbents are based on RHG-GEM baselines, which capture direct emissions, indirect emissions from electricity and heat, and any upstream fugitive emissions from fossil fuel extraction, production, and transport. These are used to calculate a global average abatement factor for each year of the projection.

For an ECT replacing an incumbent, it is assumed that each unit of the ECT replaces a unit of the incumbent technology in the market. For technologies that are carbon negative with no incumbent (such as DAC), the calculated GHG impact of the technology would be negative and can be used directly as the carbon abatement factor. As such, the carbon abatement factor is the multiplier used to calculate the proportionate relationship between installed capacity and emissions reductions directly.

$$\text{Carbon abatement factor}_y = \text{Emissions of incumbent technology per functional unit}_y - \text{Emissions of alternative technology per functional unit}_y$$

Estimate Emissions Reduction Potential

Calculating the emissions reduction potential in the baseline and catalyzed cases are straightforward. The carbon abatement factor is multiplied by the adoption curve for each case to calculate annual emissions reductions. For this simple relation to hold, it is assumed that there will be no rebound effects. The methodology used to calculate the emissions reduction potential cases is summarized below:

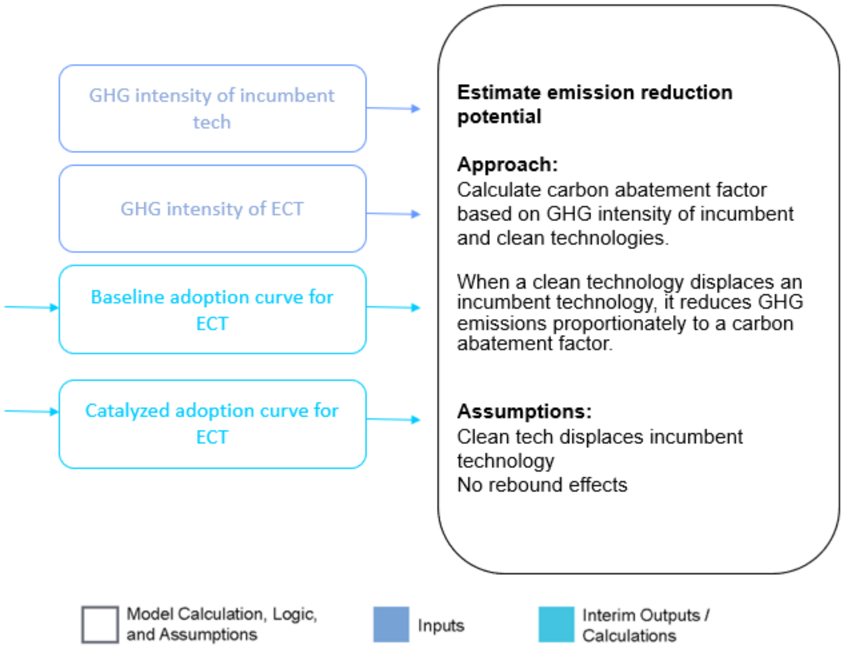

Figure 8: Summary of the Emissions Reduction Potential methodology

Calculate Catalyzed Emissions Reduction

The CatER is calculated as the difference between the curves. A discount rate is applied to account for the fact that emissions avoided sooner have a greater impact on warming.

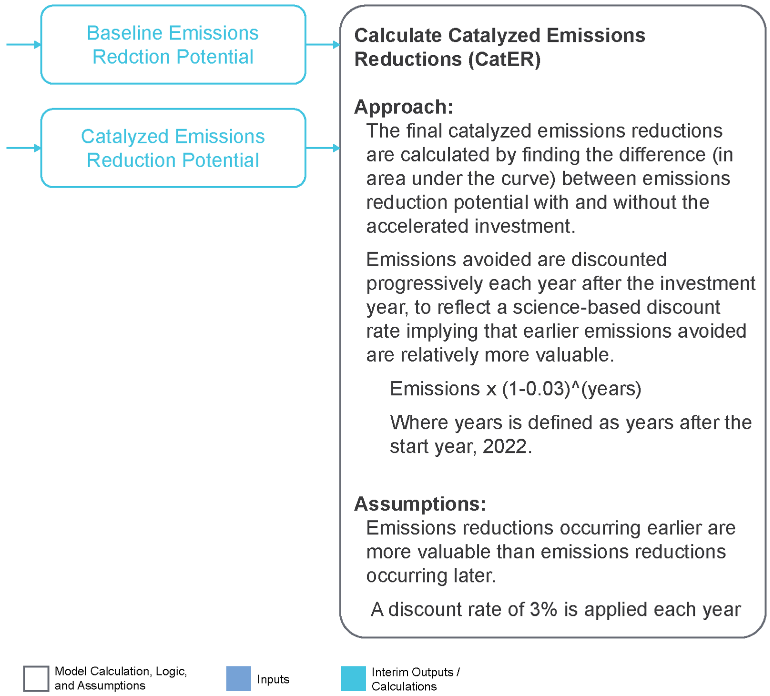

Figure 9: Summary of the Catalyzed Emissions Reduction methodology which leverages the outputs of the emissions reduction potential methodology to measure and discount the difference between the baseline and catalyzed scenarios to calculate total CatER.

Output

The output CatER metric, though conceptually straightforward, can be reported in multiple ways, adding complexity. A single aggregate number can be reported, discounted based on the methodology described above. CatER can also be reported on an in-year basis, demonstrating how emissions will have been reduced by 2050 due to the catalytic investment. This type of in-year figure is critical to track progress against net-zero targets that require a specified amount of emissions reduction (e.g., the current ~53 gigatons of annual CO_2e emissions).

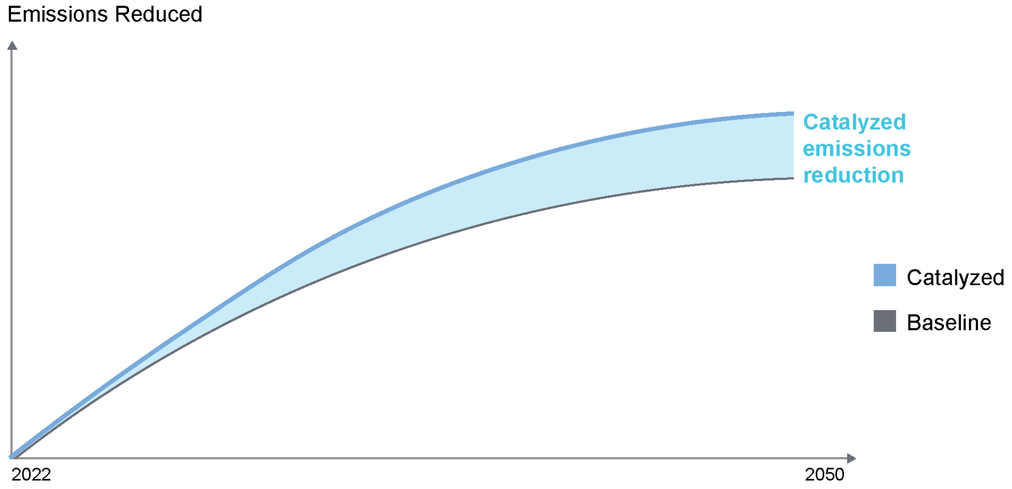

Figure 10: Illustrative catalyzed emissions reduction methodology demonstrating the difference between potential baseline and catalyzed emissions reductions

STEP 3C: ATTRIBUTE IMPACTS TO INVESTORS AND INVESTMENTS

As previously described, one of the defining features of ECTF is that metrics are calculated based on the impact investments in a specific project have on the development and subsequent impact of the ECT more broadly (beyond that specific project). Additionally, for a given ECT project, there can be multiple types of funding provided by multiple investors. As such, for each investor to measure and report on their impact (vs. the impact of the project as a whole), it is necessary to allocate measured GPR and CatER impacts based on the funding provided by each investor.

Estimating concessional capital

In some instances, investors may want to estimate the impact of purely "concessional capital" – where the investor accepts more risk and likely lower returns compared to market-rate capital due to the nascent nature of the technologies in which they are investing. There are four primary types of concessional contributions investors can make to fund an ECT project – grants, concessional debt, concessional equity, and direct offtake agreements. Across and within these four types of capital, there are varying degrees of "concessionality," which can broadly be thought of as the difference in expected return between market rate capital and concessional capital.

To value the impact of each type of concessional capital, this concept is applied to calculate "grant equivalence". Because grants are fully concessional (expecting no returns), they are treated as a 1:1 contribution in that each dollar spent is weighted as a 100% contribution to the ECT project. This stands in comparison to the other types of capital which expect some concessional return, so they are adjusted to a grant-equivalent amount. This approach is summarized in the table below:

Type of capital	Application Example	Approach to determining grant-equivalence

Grant	Providing revenue subsidies (contract for differences); buying down capital expense costs	Given that grants represent non-repayable funding, the full amount of finance disbursed through upfront grants is to be deemed as fully concessional, representing a grant element of 100%.
Concessional Debt	Subsidized debt to reduce capital expense financing costs and lower overall project weighted average cost of capital	For concessional loans, the grant element is calculated as the difference between net present value of a market-priced loan and a loan offered at softer terms. Loan instruments inherently only offer partial concessionality, representing a grant element of less than 100%.
Concessional Equity	Subsidized equity to reduce capital expense financing costs and lower overall project weighted average cost of capital	Where offered equity comes at a cost that is lower than a market-rate expected return, concessionality is introduced. Concessional equity investments will always have a grant element below 100%, given their ownership claim in the underlying asset.
Direct Offtake Agreement	Directly procuring fuel or CO_2 at a set price that enables bankability.	The concessionality of direct offtake agreements can be defined as the net present value of the Green Premium, which the offtaker commits to pay to receive a certain service or product in the future. The difference between the amount paid for the ECT and the amount that would be paid for the incumbent is considered the investment.

Table 3: Summary of types of concessional capital, example application, and approach to determining grant-equivalence required for impact attribution

Concessional capital estimation outputs

In instances where an investor wants to isolate the impact of purely concessional capital, it is possible to allocate the total impact based on a share of impact metric, which is calculated as the specific investment grant equivalent divided by the total grant equivalent for the project. Multiplying the share of impact by the total GPR or CatER results in the allocated impact. The example below demonstrates this approach for a project with total capital stack of $750M upfront plus $250M committed through offtake agreements, which generates 500k tCO_2 CatER. An identical approach could be used for GPR.

			Investment cycle				Production cycle
Instrument	**Investment**	**Terms**	**Grant element**[1]	**Grant equivalent**	**Share of impact**[2]	**CatER (tCO_2)**	**Reduced emissions (tCO_2)**[3]
Grant	$250k	—	1	$250k	52.6%	263k	—
Debt	$250k	2.5% interest[4] 10 yr duration 5 yr grace period	0.16	$41k	8.6%	57k	—
Equity	$250k	5% cost of equity[5] 10 yr horizon	0.22	$55k	11.5%	57k	—
Direct offtake agreement	$250k green premium (of $500k total contract)	Applied over 5 yrs starting in yr 6	0.26	$130k	27.3%	137k	50k
Project total	*$750k upfront + $250k offtake*			*$459k*		*500k tCO_2*	*50k tCO_2*

[1] Measure of concessionality
[2] Percent of total grant equivalent of project
[3] Direct emissions reductions that counts towards Net Zero
[4] Compared to 5.21% benchmark cost of debt
[5] Compared to 9.5% benchmark cost of equity
Note: Example adapted from CDP ECTF report, assumptions to be validated and adjusted to ensure example is realistic

Figure 11: Example illustrative impact attribution calculations for a project with total capital stack of $750M upfront plus $250M committed through offtake agreements, which generates 500k tCO_2 CatER. Detailed calculations can be found in Technical Appendix Step 3c.

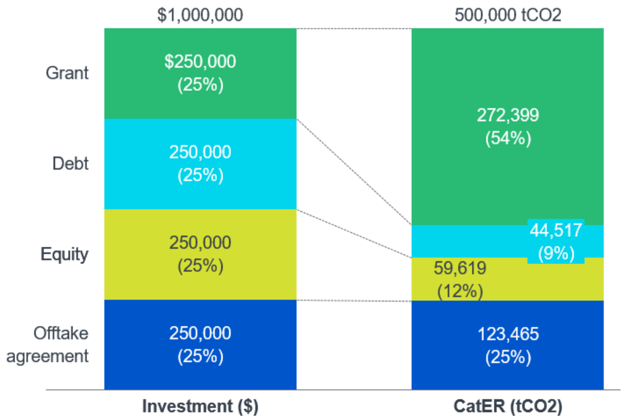

Figure 12: Investment amount and CatER allocation for illustrative attribution example, demonstrating the impact of varying degrees of concessionality for each type of capital

REPORTING

Investors should be conservative with the claims they make on the impact of catalytic investments in ECTs, as they differ from more familiar types of climate action that result in direct emissions reductions. ECT investments are considered climate contributions, defined as “the financial support provided by a company to support climate change action beyond the company’s own value chain, without claiming ownership of the emission reduction outcomes and without subtracting associated reductions from their own GHG inventory or net-zero target.”[10] Companies should be clear when reporting that CatERs are not direct emissions reductions, and should also be transparent about assumptions and limitations to this forward-looking methodology as outlined in this document.

SUMMARY OF ASSUMPTIONS

The BE ECTF model methodology makes several overarching assumptions to simplify the approach and calculations. Assumptions will be regularly evaluated and updated each year with input from stakeholders and improvements in empirical data:

Incumbent technology: Most low-carbon emerging climate technologies will displace fossil fuel-based incumbents. The model specifically identifies these fossil-fuel based incumbents. The incumbent technology that will be replaced by SAF, for example, is kerosene-based fuel. When the emerging climate technology has achieved the same cost per unit as the incumbent technology, the emerging climate technology has reached cost parity.

Market Efficiency: In general, it is assumed that the market is efficiently allocating capital to available projects that can deliver market-rate returns. In turn, it is assumed that opportunities available for catalytic investment may provide lower returns and/or be riskier than projects funded by market-rate capital.

Policy: To construct ECT deployment baselines through 2100, the model must incorporate some assumptions about how policy is likely to evolve over the course of multiple decades into the future. Net zero scenarios are not useful for this purpose because they assume all the ECT investment necessary to achieve Net Zero materializes, making the ECTF tool (which is meant to incentivize this investment at an early stage) moot. Policies will certainly evolve beyond current policy adopted or announced to date, but there is little certainty about the form or level of ambition policies may take in 2040, 2050 and beyond. For simplicity and transparency, Rhodium Group models ECT baselines under an “expected” future policy scenario based on the most straightforward proxy for climate policy – a carbon price. For more detail see Rhodium’s RHG-GEM technical appendix [link].

Treatment of Uncertainty: Given the current degree of uncertainty in global energy markets, technology, and consumer behavior, it’s important to understand the global energy system outlook under a range of uncertain future conditions. The ECTF parameterizes four key sources of uncertainty in both the baseline and catalyzed cases: 1) economic growth; 2) ECT learning rates; 3) fossil fuel market dynamics; and 4) renewable energy technology cost and performance.

---

[10] https://newclimate.org/wp-content/uploads/2022/02/NewClimate_CCRM2022_Methodoloy.pdf

Emissions Reduction Potential: The model uses abatement factors derived from RHG-GEM baselines to estimate the future emissions reduction potential due to technology displacement of the incumbent fossil fuel-based technology by the clean technology.

MODEL IMPROVEMENT OVER TIME

As with all existing impact metric frameworks, inputs and assumptions used in the current ECTF model will be updated over time as new information becomes available. In addition, the model can be expanded to include additional technologies and technology pathways as they become available. Below we outline key improvements planned for the ECTF.

Updated Deployment Baselines

Each year Rhodium will update ECT baselines under expected policy using RHG-GEM. The annual update will reflect all relevant updates to inputs and assumptions across the model, including developments in climate and energy policy across all regions, updated energy market outlooks, and any new information about ECT and incumbent technologies.

Incorporate Empirical Data on ECT Learning

One of the key challenges is predicting the forward-looking impact of catalytic capital on the ECT learning rate. In the current model, this is based on a set of assumptions as outlined above due to a lack of empirical data for these specific technologies. However, as investments ramp up, it will be possible to use the generated empirical data (the backwards looking effect of a known specific investment on the actual ECT unit cost) to validate and update assumptions such as learning rate as needed. In turn, we expect that over time, the model can be better understood and updated for the specific observed effects of investment on each ECT pathway.

Technical Appendix

GOVERNING EQUATIONS AND ASSUMPTIONS

The following section provides additional details on the model construction, assumptions, and inputs. The inputs numbers correspond to the table of inputs in the next section of the technical appendix.

Step 1: Define Baseline Adoption

RHG-GEM Model Baseline:

Description	Assumptions	Inputs
Develop a baseline for diffusion of a given technology into a given market for the technology globally. This baseline is established using Rhodium's Global Energy Model. The baseline captures a range of future diffusion pathways under key sources of technology and market uncertainty.	Technologies compete for market share based on relative cost and performance, policy, consumer behavior, and infrastructure constraints.	(1) Current cost per unit of ECT (2) Current ECT capacity (3) Learning coefficient (4) Drivers of uncertainty (e.g. expected climate policy, energy markets, etc.)

Step 2: Estimate Catalytic Effects on Adoption

Description	Assumptions	Inputs
Evaluate impacts of accelerated investment on market uptake. Accelerated investment is translated into an increase in capacity. This increase in capacity shifts the market diffusion curve so adoption is accelerated compared to a BAU scenario.	— Total time it takes for the increased investment to be absorbed by the market. — Shape of baseline curve is maintained in a scenario with catalytic capital	— (10) Baseline Adoption Curve — (7) Current cost per unit of ECT at the time(s) of investment. — (8) Investment Timing and Amounts — (9) Effective Investment

Step 3a: Assess Green Premium Reduction

Description	Assumptions	Inputs
Build learning curves. Per unit cost declines as production of clean technology scales up. Initial green premium is established as current unit cost of clean technology minus the cost of the fossil-fuel based incumbent technology. **We use single factor learning curves where the governing equation is** $C = a[Q_t]^{-\lambda}$ **Where *C* is cost, and *a* is the learning curve equation constant and is calculated as first unit cost, solved with known pairs of costs and quantity. λ is learning rate.**	— Cost decline is driven by capacity scale up. — Policies (cost of carbon) — Identity and cost of incumbent technology does not change because of ECT development	— (13) Per unit cost of carbon — (7) Current cost per unit of ECT — (4) Learning Coefficient — (14) Per Unit capital expense of ECT — (15) Per Unit operating expense of ECT — (19) LCA GHG Intensity of Incumbent Tech — (20) LCA GHG Intensity of ECT — (10) Baseline Adoption Curve for ECT — (11) Catalyzed Adoption Curve for ECT
Evaluate impacts of accelerated investment on green premium. Learning curves are used to relate cumulative number of units produced to cost declines. Accelerated investment drives the cost point of the emerging climate technology down the cost curve, which reduces the green premium.	— Cost of incumbent tech is not affected by investment in the new tech — Cost decline is a function of capacity scale-up, as influenced by investment	— Inputs from previous step above — (8) Investment timing (year of investment), and amount of investment in $USD.

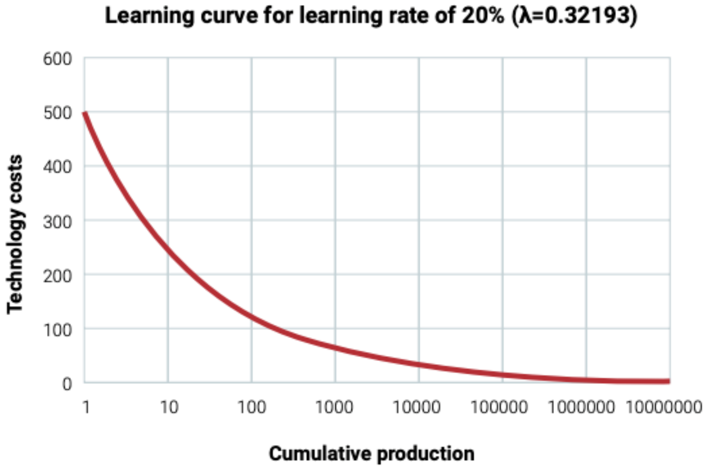

Figure A1: Learning curve showing technology cost plotted vs. cumulative production with learning rate 20% (from BE/CDP ECTF report).

Step 3b: Assess Catalyzed Emissions Reduction

Description	Assumptions	Inputs
Estimate the emissions reductions potential for the technology as a function of time.. **When a clean technology displaces an incumbent technology, it reduces GHG emissions proportionately to a carbon abatement factor.**	— Clean tech displaces incumbent tech — No rebound effects —	— (19) GHG Intensity of Incumbent Tech — (20) GHG Intensity of ECT — (10) Baseline Adoption Curve for ECT
Estimate the emissions reductions potential profile of the new technology with accelerated investment. Next estimate the additional, or catalyzed, emissions reductions that are avoided because of accelerated investment and market adoption. **These catalyzed emissions reductions occur earlier in time compared to the emissions**	— Investment translates into capacity, which accelerates market deployment — Earlier market deployment shifts emissions reductions potential earlier for the clean tech	— Inputs from previous step — (11) Catalyzed Adoption Curve for ECT

reductions that will occur in the baseline scenario.		
Calculate catalyzed emissions reductions. The final catalyzed emissions reductions are calculated by finding the difference (in area under the curve) between emissions reduction potential with and without the accelerated investment. Emissions avoided are discounted progressively each year after the investment year, to reflect that earlier emissions avoided are more valuable. This is calculated as: **Emissions x (1-0.03)^(years)** **Where years is defined as years after the start year, 2022.**	— Emissions reductions occurring earlier are more valuable that emissions reductions occurring later. — A discount rate of 3% is applied each year, meaning that in 2022 emissions avoided are valued at 100%, in 2023 they are valued at 97%, in 2024 they are valued at 94%, in 2025 at 91%, and the patterns continues until emissions avoided in 2050 are valued at 42%.	— (22) Baseline Emissions Reduction potential — (23) Catalyzed Emissions Reduction potential

Step 3c: Attribute Impacts to Investors and Investments

Description	Assumptions	Inputs
Impact attribution. The concept of "grant equivalence" is applied to capture the degree of concessionality of ECT investments in a project's capital stack and attribute project-level impact to each investor accordingly.	Impact is attributed to an investor based on the amount of money invested in a technology and the concessionality of that investment compared to a market-rate investment	— Catalyzed Emissions Reductions — Green Premium Reduction — (8) Investment Timing and Amounts — (24) Impact Attribution Rates for Project

Example Impact Attribution calculations:

Grant methodology	Example Application

$\boldsymbol{Grant\ element = 1}$ $\boldsymbol{Grant\ equivalent = Value\ of\ grant}$ $\boldsymbol{Investor\ level\ impact = \frac{Value\ of\ grant}{\sum Grant\ equivalents} \times Project\ level\ impact}$	$\boldsymbol{CatER_{grant}} = \frac{\$250{,}000}{\$458{,}886} \times 500{,}000\ tCO_2 = \boldsymbol{272,399\ tCO_2}$

Concessional debt methodology	Example Application
$\boldsymbol{Benchmark\ cost\ of\ debt = Risk\ free\ rate + Generic\ debt\ risk\ premium + Project\ debt\ risk\ premium}$ Where: • Risk-free rate = Yield on a 10-year US government bond • Generic debt risk premium = Yield on a 10-year corporate bond with a credit rating equal to the credit rating of the risk-free asset, less the risk-free rate • Project debt risk premium = Weighted average cost of debt capital provided to the project less the generic debt risk premium and the risk-free premium $\boldsymbol{Grant\ element = \frac{NPV_{benchmark\ loan} - NPV_{concessional\ laon}}{PV_{debt}}}$ $\boldsymbol{Grant\ equivalent = Value\ of\ investment \times Grant\ element}$ $\boldsymbol{Investor\ level\ impact = \frac{Grant\ equivalent_{debt}}{\sum Grant\ equivalents} \times Project\ level\ impact}$	$\boldsymbol{Benchmark\ cost\ of\ debt} = 1.46\% + 1.26\% + 2.49\% = \boldsymbol{5.21\%}$ Where: • Risk-free rate = 1.46% • Generic debt risk premium = 1.26% • Project debt risk premium = 2.49% $\boldsymbol{Grant\ element} = 1 - \left(\frac{2.5\%}{5.21\%}\right) \times \left(1 - \frac{\frac{1}{(1+5.21\%)^{(5-1)}} - \frac{1}{(1+5.21\%)^{10}}}{5.21\% \times (10-(5-1))}\right) = \boldsymbol{0.1634}$ Where: • Payments per year = 1 • Project cost of debt = 2.5% • Maturity = 10 years • Grace period = 5 years • Interval period = 4 years $\boldsymbol{Grant\ equivalent} = \$250{,}000 \times 0.1643 = \boldsymbol{\$40,857}$ $\boldsymbol{CatER_{debt}} = \frac{\$40{,}857}{\$458{,}886} \times 500{,}000\ tCO_2 = \boldsymbol{44,517\ tCO_2}$

Concessional equity methodology	Example Application
$\textit{Benchmark cost of equity}$ $= \textit{Risk free rate}$ $+ \textit{Generic equity risk premium}$ $+ \textit{Project equity risk premium}$ Where: • Risk-free rate = Yield on a 10-year US government bond • Generic equity risk premium = Historical equity risk premium observed in the US stock market over the past 10 years • Project equity risk premium = Weighted average cost of equity capital provided to the project less the generic equity risk premium and the risk-free premium $\textit{Grant element} = \frac{NPV_{benchmark\ equity} - NPV_{concessional\ equity}}{PV_{equity}}$ $\textit{Grant equivalent} = \textit{Value of investment} \times \textit{Grant element}$ $\textit{Investor level impact} = \frac{\textit{Grant equivalent}_{equity}}{\sum \textit{Grant equivalents}} \times \textit{Project level impact}$	$\textit{Benchmark cost of equity} = 1.46\% + 5.53\% + 2.41\% = \mathbf{9.5\%}$ Where: • Risk-free rate = 1.46% • Generic equity risk premium = 5.53% • Project equity risk premium = 2.51% $\textit{Grant element}$ $= \frac{\sum_{t=1}^{10} \frac{\$39{,}817}{(1+9.5\%)^t} - \sum_{t=1}^{10} \frac{\$39{,}817}{(1+5\%)^t}}{\$250{,}000}$ $= \frac{\$54{,}717 - \$0}{\$250{,}000} = \mathbf{0.2189}$ Where: • Project cost of equity = 5.0% • PV of equity investment = $250,000 • Years = 10 • Annual payment = $39,817 $\textit{Grant equivalent} = \$250{,}000 \times 0.2189 = \mathbf{\$54,717}$ $CatER_{equity} = \frac{\$54{,}717}{\$458{,}886} \times 500{,}000\ tCO_2 = \mathbf{59,619\ tCO_2}$

Offtake agreement methodology	Example Application
$\textit{Expected annual green premium payment} = \frac{(\textit{Total value of offtake agreement} \times \textit{Expected green premium}\%)}{\textit{Duration of payments}}$	$\textit{Expected annual green premium payment} = \frac{\$250{,}000 \times 50\%}{5\ years} = \$25{,}000/year$

$\boldsymbol{WACC} = \boldsymbol{Weighted\ cost\ of\ grant} + \boldsymbol{Weighted\ cost\ of\ concessional\ debt} + \boldsymbol{Weighted\ cost\ of\ concessional\ equity}$ $\boldsymbol{Grant\ element} = \boldsymbol{NPV_{expected\ green\ premium\ payments}}$ Where: • Expected green premium = 50% of total cost • Premiums are paid in equal installments over 5 years, starting in year 6 • Discount rate for premiums = Weighted average cost of total capital provided to the project $\boldsymbol{Grant\ equivalent} = \boldsymbol{Value\ of\ investment} \times \boldsymbol{Grant\ element}$ $\boldsymbol{Investor\ level\ impact} = \frac{\boldsymbol{Grant\ equivalent_{offtake}}}{\sum \boldsymbol{Grant\ equivalents}} \times \boldsymbol{Project\ level\ impact}$	$\boldsymbol{WACC} = \frac{\$250{,}000}{\$750{,}000} \times 0\% + \frac{\$250{,}000}{\$750{,}000} \times 2.5\% + \frac{\$250{,}000}{\$750{,}000} \times 5\% = \mathbf{2.5}\%$ $\boldsymbol{Grant\ element} = \frac{\sum_{t=6}^{10} \frac{\$25{,}000}{(1+2.5\%)^t}}{\$250{,}000} = \frac{\$113{,}313}{\$250{,}000} = \mathbf{0.4533}$ $\boldsymbol{Grant\ equivalent} = \$250{,}000 \times 0.4533 = \$\mathbf{113,313}$ $\boldsymbol{CatER_{offtake}} = \frac{\$113{,}313}{\$458{,}886} \times 500{,}000\ tCO_2 = \mathbf{123,465\ tCO_2}$