IEc

Evaluation of the Development Impacts from CIF's Investments

Memorandum on Modeling Approaches to Measure Development Impacts

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Prepared for:

Climate Investment Funds

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TO Climate Investment Funds (CIF)

FROM Industrial Economics, Incorporated (IEc)

SUBJECT Modeling Approaches, Tools, and Recommendations to Measure the Development Impacts of Climate Investment Fund (CIF) Programs

ACKNOWLEDGMENTS

This memorandum was prepared by Industrial Economics (IEc) as part of an independent evaluation commissioned by the Climate Investment Funds (CIF) to examine CIF's contribution to development impacts through its climate investments.

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1. INTRODUCTION

Established in 2008, the Climate Investment Funds (CIF) provide scaled-up climate financing to developing countries to support transformational change towards low-carbon, climate-resilient development. CIF started with two funds: the Clean Technology Fund (CTF) and the Strategic Climate Fund (SCF). The latter includes three targeted programs: Scaling-Up for Renewable Energy Program (SREP), the Pilot Program for Climate Resilience (PPCR), and the Forest Investment Program (FIP). In the summer of 2021, CIF announced the establishment of three new programs: Accelerating Coal Transition (ACT), Nature, People, and Climate (NPC), and Renewable Energy Integration (REI).

When considering the impacts of CIF investments, CIF stakeholders have recently articulated an interest and need to document the contributions that CIF programs are making above and beyond its core climate change objectives—that is, contributions also related to national social and economic development objectives, and/or the UN's Sustainable Development Goals (SDGs). These additional development impacts—which are sometimes called "co-benefits"—include, among others, job creation, economic activity, improvements in health and safety, market development, social inclusion, and greater gender equality. In the absence of core indicators, baselines, and targets comparable to those used to track CIFs climate impacts, these development impacts are generally difficult to assess and measure. However, there is consensus that if climate investments can also deliver social and economic impacts, the business case for increased and more ambitious climate finance is significantly stronger. A more robust and nuanced understanding of these development impacts can also enable climate financiers and development practitioners to maximize co-benefits.

In recognition of the importance and value of these development co-benefits, CIF launched a new workstream in 2019: the Social and Economic Development Impacts of Climate Investments (SEDICI). This memorandum is one component of a wider evaluation that Industrial Economics, Inc. (IEc) is conducting for CIF as part of that workstream. Another component involved five country- and sector-specific deep dive case studies focused on evaluating the benefits of specific CIF investments. These include analyses of: (1) agricultural production in Bangladesh, (2) geothermal energy generation in Indonesia, (3) air quality improvements in Thailand, (4) ecosystem services in Brazil, and (5) biogas energy production in Nepal.

This memorandum focuses on portfolio-level analyses and, specifically, on modeling approaches that CIF may be able to use or is already using (e.g., JIM) to analyze CIF investments for selected development impacts. We begin by providing a high-level assessment of the suitability for modeling of 14 priority development impacts (DIs). Next, we scope and provide recommendations on modeling tools for a subset of DIs. Lastly, we critically review the JIM tool to recommend ways to a) improve CIF's use of the tool in the immediate term, and b) improve or enhance the tool in the longer term.

2. PRIORITY DEVELOPMENT INDICATORS—HIGH-LEVEL ASSESSMENT FOR MODELING POTENTIAL

As part of the Secondary Information Review previously conducted for the wider evaluation on development impacts, the IEc team developed a comprehensive taxonomy of approximately 70 DIs, organized into 11 impact areas. Specifically, the IEc team reviewed the following information:

- Results Frameworks of CIF's original four programs (CTF, FIP, SREP, and PPCR) to understand existing indicators used to document the impact of CIF investments;
- An in-depth characterization of development impacts of the four original CIF programs, previously conducted as part of this evaluation; and
- Integrated Results Frameworks developed for the new CIF programs announced in 2021 (ACT, NPC, and REI).

Based on a review of the above information, we identified a subset of development impact areas to serve as the focus of the analysis described in this memorandum. The IEc team shared the initial list of development impact areas with CIF staff, who identified a set of DIs that are of high priority across the current CIF programs (see **Table 1**).

Table 1. Subset of High-Priority Development Impacts across CIF Programs

Development Impact Area	Development Impact
Social: Livelihoods, wealth, and quality of life	1. Increased or diversified income
	2. Increased abilities to cope with shocks; reduced losses from climate events
Social: Health and safety	3. Avoided health impacts from reduced (or avoided) fossil fuel combustion
Economic: Employment opportunities	4. Increase in direct employment 5. Increase in indirect & induced employment 6. Increase in energy enabled employment 7. Increase in high quality employment
Economic: Value added	8. Increase in economic output (direct/indirect/induced) 9. Increase in economic output (energy enabled)
Environmental: Ecosystems and biodiversity	10. Improved air quality
Markets: Energy sector security and resilience	11. Improved energy sector integration 12. Increased local energy generation
Markets: Competitiveness and industrial development	13. Increased supply chain/SME development 14. Increased agricultural productivity

EVALUATION CRITERIA

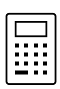
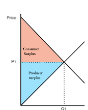
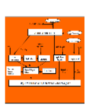
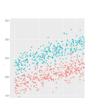
In this section, we evaluate the above DIs at a high level, to identify which subset may warrant additional investment of resources by CIF. The DIs are evaluated according to five criteria:

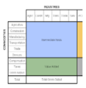
1. Do **modeling approaches exist** in the literature for this DI? The goal of this question is to understand whether researchers have developed ways to quantify the DI, as an initial step to understanding if it can be modeled.

2. Across which **modeling approaches** are the specific models identified for this DI? Overly complex or involved modeling approaches may not be suitable for broad application by CIF. **Table 2** below provides an overview of different categories of biophysical and economic modeling approaches, along with their levels of complexity.
3. At what **spatial scale** can this DI be modeled with adequate confidence levels? For instance, can the DI be modeled at the global, regional, national, subnational, or local scale? DIs that can be evaluated at a regional or global scale are candidates for portfolio level analysis.
4. Over what **timeframe** can this DI be modeled with adequate confidence levels? There are two components to this question: (a) What time step of input data do models need to produce reliable results (e.g., crop models can use monthly climate data, but daily will produce more reliable results)? (b) How long a historical record is needed to parameterize models?
5. Are there **existing modeling tools** in the public or private domains for this DI? This question is a threshold criterion. If existing modeling tools are not available for a specific DI, then it is not feasible for the DI to move on to the next stage of the analysis.

Related to the second criterion above, **Table 2** presents six categories of economic modeling approaches. These are drawn from work IEc conducted for the World Bank as part of an advisory activity on the economics of investments to promote water security, but are more broadly relevant to investments in energy, agriculture, and other sectors.

Table 2. Economic Modeling Approaches

Modeling Approach	Description
 **Accounting**	Accounting analyses involve gathering quantitative data, typically counts, on historical or anticipated performance of the investment, and where applicable, applying a unit cost or price. For example, a hydropower project may have generated 10,000 MWh per year at a wholesale rate of $80/MWh, producing $800,000 per year in revenues. **Level of complexity:** Simplest, but least reliable option, appropriate for basic benefits approximations in some cases.
 **Partial Equilibrium**	Partial equilibrium (PE) analysis does well when analyzing investments/programs that have marginal impacts on resource supply and/or demand, e.g., in the context of water resources, a small reservoir, local water supply, mini-hydro, or conversion of limited rainfed to irrigated. PE analyses use current market prices or alternative measures to estimate "the benefits, to whomsoever they may accrue, are in excess of the estimated costs" within classic cost-benefit analysis. **Level of complexity:** Varies widely based on the complexity of the system being modeled and whether a user interface is available. Some PE models may be usable by CIF internally, whereas others would require outside consultation.
 **Optimization**	Optimization models use regional-scale analysis to allocate resources across economic sectors—agricultural, energy, industrial, domestic, and ecosystems—within an optimization framework. Optimal allocation is prescribed using the marginal value of the resource to these sectors with the shadow prices of all constraints estimated. **Level of complexity:** Tend to be more complex and programming-intensive, and can require nuanced interpretation of results given the potential for optimization models to arrive at local maxima (rather than "global maxima") or corner solutions.
 **Econometrics**	The essential input into an econometric model is a data set describing the historical behavior over time of variables of interest. A critical assumption is that the distribution of the relationship between explanatory and dependent variables will be the same in the future as it was in the past, and is thus invariant to the change in policy regime that policy interventions necessarily entail.

Modeling Approach	Description
	Level of complexity: Varies from simple regressions to very involved econometric models, depending on the system being modeled and data available. Based on our experience, there are fewer off-the-shelf econometric models—most are customized to specific contexts.
 **Input-Output Analysis**	Input-output (I-O) analysis represents the economy as the linear interdependencies between economic sectors. The foundation of I-O analysis involves input-output tables. Such tables contain data that quantify the supply chain for all sectors of an economy. I-O models estimate three types of impact: direct, indirect, and induced that ripple throughout the economy when a change is made to a given input level. **Level of complexity**: Given the linear relationships in these models, if reliable input data and a straightforward user interface are available, these models can be straightforward. JIM is a good example.
 **General Equilibrium**	Computable general equilibrium (CGE) models capture all income and expenditures within an economy based on a social accounting matrix (SAM). Production is disaggregated across sectors within agriculture, industry, and services. Economic sectors employ factors of production (land, labor, and capital) to produce goods and services that are supplied to product markets capturing full circular flow of goods and incomes between households and sectors. Production and demand functions are nonlinear. CGEs can be static annual or dynamic growth models. **Level of complexity:** Requires facility with CGE models and a solid understanding of macroeconomics. Would require an outside team to develop a system that CIF could apply, much like JIM. Such a system would require periodic updating and maintenance.

HIGH-LEVEL EVALUATION OF DEVELOPMENT INDICATORS

Table 3 provides a high-level, qualitative assessment of the suitability for modeling and evaluation of each DI described in **Table 1** above. The first evaluation question considers whether modeling approaches have been identified in the literature, and the fifth column considers whether there are off-the-shelf models readily available. For most DIs, we found that both modeling approaches and off-the shelf models exist, but the complexity of the available models for some DIs means they may be challenging for CIF to deploy, given the level of resources and data inputs required.[1] This overarching finding is captured in the responses to the fifth question, in italicized, bold text. As shown in this column, JIM already covers four of the DIs adequately. For three other DIs, our screening analysis suggests the DIs are too challenging for CIF to pursue, either because the modeling approach is unclear or too complex. This leaves seven DIs that we recommend as promising candidates for further consideration.

[1] By complexity, we mean that the models (a) require considerable resources to run given the topical (e.g., hydrology, agronomy) and programming expertise required, and/or (b) have potentially expansive data input requirements that themselves can require modeling to develop (e.g., rainfall-runoff and crop water demand models translate climate data into inputs for water systems models). Many of these models also require calibration and validation procedures using detailed time series data to ensure local/regional conditions are adequately represented.

Table 3. Modeling Feasibility for the 14 Development Indicators

Development Impact	Evaluation Questions									
	1. Do **modeling approaches exist** in literature?	2. **Modeling Approach**?						3. At what **spatial scale** can this be modeled with adequate confidence levels?	4. Over what **timeframe** can this DI be modeled with adequate confidence levels?	5. Are there **existing modeling tools** in the public or private domains for this DI?
		Accounting	Partial Equil.	Optimization	Econometrics	I-O Analysis	General Equil.			
1. Increased or diversified income	Yes: Aim is to understand how different income groups are affected.	✓	-	-	✓	✓	✓	Local, sub-national, national	Time step: Annual Record length: Varies based on objective	Not an off the shelf tool, to our knowledge. Important to clarify how this DI is defined - e.g., in terms of reduced inequality, diversified income across sectors, etc. ***Challenging*: *unclear modeling approach***
2. Increased abilities to cope with shocks; reduced losses from climate events	Yes: Numerous models could serve this purpose -- agricultural, flooding, energy, sea level rise, etc. Outputs can be channeled into CGE models.	-	✓	✓	✓	✓	✓	Local, sub-national, national, regional, global	Time step: Daily, monthly, annual Record length: varies, ideally 10 years	Yes: sectoral models primarily such as AquaCrop, WEAP, or others (see Appendix A for description) ***Promising***
3. Avoided health impacts from reduced (or avoided) fossil fuel combustion	Yes: Health-emissions models that take inputs from air quality models (DI10). Can also route outputs to CGE to analyze macro effects.	-	✓	✓	-	-	-	Local, sub-national, national, regional	Time step: Hourly to monthly Record length: Varies based on objective	Yes: BenMap, LEAP (see Appendix A for description) ***Promising***
4. Increase in direct employment	Yes: I-O models (and CGEs). Also, a macro-econometric model that EPA routinely uses.	-	-	-	✓	✓	✓	Local, sub-national, national, regional, global	Time step: Annual Record length: Varies based on objective	Yes: JIM. KLEMS models (Dale Jorgensen). ***JIM already covers***
5. Increase in indirect & induced employment	Yes: Same as DI4.	-	-	-	✓	✓	✓	Local, sub-national, national, regional, global	Time step: Annual Record length: Varies based on objective	Yes: JIM ***JIM already covers***
6. Increase in energy enabled employment	Yes: Same as DI4	-	-	-	✓	✓	✓	Local, sub-national, national, regional, global	Time step: Annual Record length: Varies based on objective	Yes: JIM ***JIM already covers***

Development Impact	Evaluation Questions									
	1. Do **modeling approaches exist** in literature?	2. **Modeling Approach**?						3. At what **spatial scale** can this be modeled with adequate confidence levels?	4. Over what **timeframe** can this DI be modeled with adequate confidence levels?	5. Are there **existing modeling tools** in the public or private domains for this DI?
		Accounting	Partial Equil.	Optimization	Econometrics	I-O Analysis	General Equil.			
7. Increase in high quality employment	Yes: JIM assumptions, Harris-Todaro economic model or simple econometric approach.	✓	-	-	✓	✓	-	Local, sub-national, national, regional, global	Time step: Annual Record length: Varies based on objective	Yes: JIM to some extent, although coarse. ***JIM already covers***
8. Increase in economic output (direct/ indirect/ induced)	Yes: I-O models and CGEs	-	-	-	-	✓	✓	Local, sub-national, national, regional, global	Time step: Annual Record length: Varies based on objective	Yes: JIM. Also Envisage CGE Model from GTAP ***Promising, to complement JIM***
9. Increase in economic output (energy enabled)	Yes: I-O models and CGEs	-	-	-	-	✓	✓	Local, sub-national, national, regional, global	Time step: Annual Record length: Varies based on objective	Yes: JIM, GTAP CGEs (see Appendix A for description) ***Promising, to complement JIM***
10. Improved air quality	Yes: air quality modeling tools, projections based on local conditions (inputs to DI3).	-	✓	✓	✓	-	-	Local, sub-national, national, regional, global	Time step: Hourly to monthly Record length: Ideally 10+ years	Yes: GEOS-Chem is a global public domain tool (see Appendix A for description) ***Promising, although modeling may be too complex.***
11. Improved energy sector integration	In principle, CGEs can do this, or a bottom-up model.	-	✓	-	-	-	✓	Unclear	Unclear	Assuming the focus is on renewables integration? What aspects? Sector-wide? OSeMOSYS? ***Challenging: involves complex modeling***
12. Increased local energy generation	Yes: Power Pool models, energy planning models, dispatch capacity expansion models. Then sector models e.g., water system models for hydro.	✓	✓	✓	-	-	-	Local, sub-national, national, regional (e.g., multi-country Power Pools)	Time step: Varies. Hourly for dispatch models. Record length: Varies based on objective	Yes: OSeMOSYS (power pool model), PLEXOS, WEAP (hydropower) ***Promising***

Development Impact	Evaluation Questions									
	1. Do **modeling approaches exist** in literature?	2. **Modeling Approach**?						3. At what **spatial scale** can this be modeled with adequate confidence levels?	4. Over what **timeframe** can this DI be modeled with adequate confidence levels?	5. Are there **existing modeling tools** in the public or private domains for this DI?
		Accounting	Partial Equil.	Optimization	Econometrics	I-O Analysis	General Equil.			
13. Increased supply chain/SME development	Not aware of modeling approach. If elements of a production process are moved to a country, a CGE can model this at a screening level.	-	-	-	-	-	-	Unclear	Unclear	Not aware of an off-the-shelf model. Need to clarify focus and how will it be measured. Localization requirements? ***Challenging*: *unclear modeling approach***
14. Increased agricultural productivity	Yes: biophysical and statistical crop models. Can be disagreement between statistical and biophysical approaches. Need to consider water if irrigation is focus. Ag outputs can be inputs to I-O and CGE models for macro effects.	-	⍰	-	⍰	-	-	Local, sub-national, national, regional, global	Time step: Daily, monthly, annual, decadal Record length: Ideally 10+ years monthly data	Yes: AquaCrop, DSSAT, EPIC (see Appendix A for description) ***Promising***

3. SCOPING AND RECOMMENDATIONS ON MODELING APPROACHES/TOOLS

Based on the above, in collaboration with CIF, we selected three groups of DIs that appear most promising for potential application to CIF programs' portfolio (**Table 4**), including six of the seven promising options in the table above. This scoping is intended to assess existing tools to analyze those Dis available in the marketplace (public or private) that CIF could potentially access, license, or adapt for its own use.

Table 4. DI Categories Assessed in Depth

DI Category	Development Impacts	Scope of Assessment
1. Improved air quality and resulting health benefits	3. Avoided health impacts from reduced (or avoided) fossil fuel combustion 10. Improved air quality	Air quality tools feed into health impact tools, so these are assessed together
2. Increased climate resilience in agriculture	2. Increased abilities to cope with shocks; reduced losses from climate events 14. Increased agricultural productivity	High-level summary of tools that address increased ability to cope with and adapt to climate impacts related to agriculture
3. Increased energy-enabled economic output	8. Increase in economic output (direct/ indirect/ induced) 9. Increase in economic output (energy enabled)	Covering tools that evaluate economic output, with a focus on tools that can evaluate energy enabled output.

Our assessment focuses on the main characteristics of the tools, with CIF's needs and capabilities in mind. Some of these considerations include: (1) **level of complexity** as it relates to technical requirements for data, people, or computation in the context of CIF's capabilities; (2) **in-house vs. outsourced** use of the tool; (3) **estimated costs** of implementation and ongoing maintenance; (4) **examples of where this tool has been used,** by others or in CIF case studies as applicable; and (5) **CIF primary use cases for modeling.**[2]

On the last consideration, there are several ways in which CIF might use the results of development impact modeling in its programmatic work. **Table 5** presents several use cases to help illustrate how CIF could use the information in this memorandum.

[2] As noted above, in another component of the wider evaluation by IEc, we conduct case studies focused on evaluating the benefits of specific CIF investments in Bangladesh, Indonesia, Thailand, Brazil, and Nepal. Of relevance to the DI categories explored in this deep dive, the Bangladesh study focuses on agricultural productivity resulting from polder investments, the Thailand case study analyzes the health benefits of reduced fossil emissions, and the Indonesia case study focuses on economic output resulting from geothermal investments.

Table 5. CIF Primary Use Cases for Modeling

Primary Use Case	Description
1. Investment plans and project design	Diagnostics, ex-ante estimations, and scenario analyses: During the investment planning and project design processes, countries, MDBs, and their project leads could utilize CIF-supported models or tools to gain cogent insights regarding investment plan and project design elements to ground theoretical analyses on economic data, and to refine the design to enhance potential development impacts. The finding could also be used to establish baseline data/markers at the country or program level, as a starting point from which to periodically track progress over the life of the investment program. This would also aid in fine-tuning future diagnostic approaches, and in validating or improving on programs' theories of change and related assumptions.
2. Exploration and collaboration with partners	Enhanced knowledge: CIF works with many types of stakeholders, including MDBs, national governments of project countries, donor governments, and others. Bringing new, easy to access tools or insights to partners can help enhance discussions regarding development impact pathways, and guide decision-making towards more optimized outcomes. They could also provide a means for stakeholders to dissect their country- or project-level theories of change, via evidence-based analyses of impact pathways, assumptions, and potential risks and alternate scenarios.
3. Understanding trade-offs between investment opportunities	Project proponents are choosing between different types of interventions—e.g., between different technologies, different investment sites, or other factors, but they often do not understand the "full picture" of potential benefits or resulting negative impacts. Models that can provide a more "net" or holistic view of outcomes are valuable in such cases.
4. Ex-post evaluation of development impacts from climate finance	Ex-post estimations: After and while projects are implemented, countries, MDBs, and their project leads would utilize CIF-supported models or tools to gain cogent insights regarding project performance. This is the process conducted in our five case studies.

PRELIMINARY RECOMMENDATIONS ON TOOLS FOR EACH DI CATEGORY

Based on a review of several models in each package according to the criteria above (see **Appendix A** for a review of models), below we recommend a single model or set of models in each category that we think will best accommodate CIF's needs for scalability, rapid deployment, and analytical rigor.

Category 1: Improved air quality and resulting health benefits (DI3, DI10)

As part of our screening assessment, we considered two types of potentially relevant models: (1) those designed to model changes in air quality, which are more complex and less user-friendly, and (2) those designed to model health benefits, with a simpler, but adequate approach to air quality. One candidate for more detailed air quality modeling is **GEOS-Chem**, a publicly available tool developed and maintained by Harvard University. While the tool allows for detailed air quality modeling at a variety of spatial scales, the model's hardware and software requirements are fairly involved, and using it requires someone with solid programming knowledge, and ideally a background in atmospheric chemistry.

Much more user-friendly models are available to analyze energy-related emissions and health benefits of air quality improvements. Two promising models in this category are **LEAP** (Low Emissions Analysis Platform) and **BenMap**.

LEAP was developed by the Stockholm Environment Institute (SEI) and is a scenario-based modeling tool used for policy analysis and to consider the economic and environmental effects of various programs and investments. The tool is well supported by SEI, is designed to be user-friendly, and is free to academics, governments, and NGOs. We have also applied LEAP as part of the Thailand case study within our wider study. LEAP-IBC (Integrated Benefits Calculator) is a variant of LEAP that allows for a more detailed analysis of the benefits of emissions changes, and is thus relevant to CIF's objectives.

BenMap is also a widely used, well supported tool that could also be useful for CIF. Developed by the U.S. Environmental Protection Agency (EPA), it is used to quantify the health and economic impacts of changes in air quality—specifically, fine particles and ground-level ozone. Health impacts are quantified through a health impact function. Economic values are calculated through the costs of illness and willingness-to-pay metrics. The tool has been applied in numerous settings, and IEc currently is working with the EPA and the World Bank to apply it in international contexts.

Both LEAP and BenMap appear to be good options for CIF to consider for health impacts modeling. These tools incorporate sufficiently robust emissions modeling for project and portfolio benefits estimation without including a more detailed atmospheric chemistry model such as GEOS-Chem. As we applied LEAP in the Thailand case study and are thus more familiar with the tool and its application, we summarize details on this software tool below. Details on BenMap are provided in Appendix A.

LEAP (Low Emissions Analysis Platform)	
Description	LEAP is a scenario-based modeling tool primarily used for energy policy analysis and climate change mitigation assessments. LEAP can act as a forecasting tool to consider energy supply and demand and a policy tool to consider economic and environmental effects of various energy programs and investments. LEAP-IBC (Integrated Benefits Calculator) allows analysis of energy-related emissions and resulting health impacts.
URL	https://leap.sei.org/default.asp?action=home
Complexity and data needs	LEAP has been designed to be accessible for decision-makers and those involved in energy and climate policy. There are low data requirements necessary to get started with LEAP, and therefore it can be used in developing countries, which may have limited data availability. Data requirements for LEAP's demand analysis include demographic data, macroeconomic data, and energy data (e.g., national balances, mitigation assessments, energy prices, energy supply).
In-house vs. outsourced use	LEAP is an open-source tool designed to be accessible for individuals with limited modeling background; in-house use by CIF therefore seems very possible.
Cost of implementation and maintenance	The LEAP tool and its training materials are free to academics, governments, and NGOs based in low- and middle-income countries, in addition to all students. For businesses and utilities, LEAP must be accessed through its licensing agreements, the costs of which range from US$500 to $3,000.
Examples of use	Applied to evaluate air quality improvements and health benefits as part of the Thailand case study on large-scale wind. Also, "Energy Efficiency Plan Benefits in Ecuador: Long-range Energy Alternative Planning Model" (*International Journal of Energy Economics and Policy*, 2018) Paper uses LEAP to forecast annual energy demand until 2035 in Ecuador.
Use cases for CIF	(1) Investment Plans and project design: LEAP could help guide a country's energy investments by modeling economic and environmental impacts while also considering the demographic and macroeconomic context of a country. Also, through its ability to forecast energy demand, LEAP could be useful in guiding investment plans and project design. (2) Exploration and collaboration with partners: LEAP is designed to be accessible to users who do not have a hard science background. This makes it usable by different stakeholders and could promote collaboration. (3) Understanding trade-offs between investment opportunities: LEAP allows for evaluation of various interventions to improve air quality and human health. (4) Ex-post evaluation of development impacts from climate finance, as demonstrated in the Thailand case study.
Outputs / Units	Depending on model specifications, LEAP can have numerous outputs. Outputs related to energy supply and demand metrics can be displayed as energy balance tables. These tables can be viewed for various fuels, years, scenarios, regions, and subsectors. Demand and supply metrics can be displayed in almost any unit of measurement and in various numeric formats (i.e., absolute values, growth rates, percentage shares, etc.).

Category 2: Increased climate resilience in agriculture (DI2, DI14)

The DI of "increased abilities to cope with shocks; reduced losses from climate events" (DI2) is quite broad and encompasses potentially hundreds of models that analyze impacts and adaptation options across multiple sectors. To make the category tractable, we have merged it with the DI "increased agricultural productivity" (DI14), and we consider models that allow analysis of measures to build resilience to climate change impacts on agriculture. The agricultural sector is also quite broad—for the purposes of this memorandum, we constrain our evaluation to models of rainfed and irrigated cropping systems, as there are several pre-existing and relatively user-friendly crop and water availability models in the public domain, and we are not aware of similarly accessible models of livestock systems or other agricultural value chain components that would be suitable for CIF.

Several well-established models for evaluating climate change effects on crop production are reviewed in Appendix A.[3] Of these, **AquaCrop** appears to be one of the best options, for its combination of analytical rigor, widespread use, and relatively straightforward application. The model takes daily climate inputs to analyze crop yields under different climate futures, and can be parameterized to evaluate a wide range of interventions (e.g., crop switching, heat-tolerant varieties, improved soil-water management, irrigation). The tool does not have as straightforward or polished a graphical user interface as LEAP, but its interface does not require a programming language to use. Processing necessary climate inputs would benefit from basic knowledge of R, Python, or MATLAB. If AquaCrop is too complex a tool for CIF, the UN Food and Agriculture Organization (FAO) and others have simpler options that take monthly, instead of daily, climate inputs, including AquaCrop's predecessor, **CropWat**. However, these models focus only on the effect of rainfall on crop yields, rather than the broader set of factors considered in AquaCrop (e.g., temperature, salinity, CO_2 concentrations).

Note that AquaCrop has no capacity to model upstream water availability, which is critical to understand the potential benefits of irrigation investments. The **Water Evaluation and Planning (WEAP)** tool, developed by SEI, is a user-friendly water systems model that allows users to construct a network of rivers, reservoirs, withdrawals, and flow requirements to understand how climate change and competing uses of water may affect water availability throughout a system of river basins. To understand the potential benefits of irrigation investments, we have in previous projects used a combination of AquaCrop to understand crop yield response to irrigation water inputs, and WEAP to understand system-wide water availability for irrigation withdrawals (see example of use in the AquaCrop table below). Importantly, WEAP also allows for analysis of monthly hydropower generation within the water system.

The table below describes AquaCrop characteristics, which we describe here for its direct application to evaluating changes in agricultural productivity; additional details on WEAP are provided in Appendix A.

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[3] Although not reviewed in Appendix A, as it is not a traditional crop model, another potentially useful and relevant tool is the **Soil & Water Assessment Tool (SWAT)**. SWAT is a river basin model used to "simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds." (See https://swat.tamu.edu/docs/.) This may be a useful tool for CIF to evaluate projects that enhance land use and improve water quality.

AquaCrop	
Description	Developed by the FAO, AquaCrop is a crop growth model that quantifies biomass, crop production, and performance indicators in response to changes in water supply specifically for herbaceous crops. There is also a MATLAB version of the tool available through the University of Nebraska that allows for much faster processing, when large geographic areas or numerous scenario runs are needed.
URL	https://www.fao.org/aquacrop
Complexity and data needs	Running AquaCrop requires information on weather conditions, crop conditions, management conditions (i.e., field management, irrigation management), and soil conditions (i.e., soil profile and groundwater conditions). AquaCrop contains data on mean annual atmospheric CO_2 and tools to compute evapotranspiration. However, other data requirements must be entered by the user. Meeting these data requirements would benefit from an understanding of R, Python, MATLAB, or another similar data processing programming tool.
In-house vs. outsourced use	AquaCrop was designed to be used by a range of practitioners outside of the scientific community, and thus assumes a simplified relationship between biomass production and crop transpiration, which ultimately requires fewer data inputs compared to other models used in the scientific community. The accessibility of some data components within the model makes in-house use of AquaCrop seem more feasible than other options.
Cost of implementation and maintenance	The AquaCrop Windows program can be downloaded through the FAO website for free. Users must provide their contact information to FAO when submitting a download request. The University of Nebraska version of the tool is limited in its commercial application but is free for academic institutions and NGOs.
Examples of use	World Bank. 2013. Looking Beyond the Horizon: How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia. https://openknowledge.worldbank.org/handle/10986/13119?show=full Also applied to evaluate potential effects of salinization in the Bangladesh agriculture case study on the benefits of polder investments.
Use cases for CIF	(1) Investment plan and project design: By simulating crop yields as a function of different water supply conditions, AquaCrop can be helpful in identifying crops most vulnerable to changing environmental conditions. By identifying these crops, water management investments can be targeted towards farming areas that will be most impacted. (2) Exploration and collaboration with partners: AquaCrop results are easy to communicate and understand. As noted above, it is not the most user-friendly tool, but it is very powerful once learned. (3) Understanding trade-offs between investment opportunities: AquaCrop allows for evaluation of various interventions to improve yields and thus food security. (4) Ex-post evaluation of development impacts from climate finance, as applied in the Bangladesh case study.
Outputs / Units	The main model output from AQUACROP is dry yield formation measured in tons/ha, and irrigation water demand, measured in mm. There are also several other secondary outputs including, for instance, volume of fertilizer application.

Category 3: Increased energy-enabled economic output (DI8, DI9)

This category focuses on tools that can evaluate changes in economic output resulting from energy investments. Appendix A reviews a set of I-O and CGE models, including one integrated global economic modeling platform (GCAM) that includes agricultural, energy, and other sectoral modules. The JIM already has the capability to analyze energy-enabled output, but unlike CGE models, it does not allow for analysis of the economy-wide implications of investments—see Section 4 for more detail on this topic.

We recommend that CIF consider two activities to better quantify energy-enabled economic output, both of which would require more time and resources than the options recommended in the previous two sector-specific categories. The first is to develop a CGE modeling framework to allow for economy-wide project and portfolio analysis, and the second is to develop a set of broadly applicable, screening-level sectoral models that can generate inputs to macro models (either JIM or a CGE framework).[4]

The first activity would involve teaming up with another organization that already has access to a CGE modeling platform, to tailor that platform to CIF's needs. To our knowledge, three groups may be promising collaborators:

- The **Massachusetts Institute of Technology (MIT)** Joint Program on the Science and Policy of Global Change, to develop a more generalized and user-friendly version of its Emissions Prediction and Policy Analysis (EPPA) model—see the table below and Section 4 for more details. This is a global CGE model that draws on GTAP country-level data, and would allow for more integrated analysis of CIF's investment portfolio. Dr. Sergey Paltsev, who is one of the lead EPPA modelers and a team member on this activity, has expressed interest in this concept.
- The **Global Trade Analysis Project (GTAP)** team at Purdue University, to enhance their existing set of CGE models into a framework more like JIM. This may be the most straightforward approach given the uniformity across the GTAP CGE models.
- The **World Bank**, to stitch its existing set of macro models into a more cohesive framework. The Bank uses its MANAGE CGE model in some countries, and the MFMod macro-structural model in others. If it is feasible to collaborate with the World Bank on these analyses, it may be most suitable for project-level analysis, given differences in model structure across countries.

The table below summarizes the applicability of MIT's EPPA model.

Emissions Prediction and Policy Analysis (EPPA)	
Description	Developed by the MIT Joint Program on the Science and Policy of Global Change, EPPA is a CGE model used for economic projections and policy analysis. EPPA allows users to quantify the economic impact of emission mitigation policies (emissions limits, carbon taxes, energy taxes, tradeable permits, and technology regulation) and also model how different emission scenarios influence atmospheric chemistry and climate change. EPPA can be run as a standalone model or in conjunction with MIT Earth System Model.
URL	https://globalchange.mit.edu/research/research-tools/human-system-model/download
Complexity and data needs	The global trade analysis project (GTAP) database is built into the EPPA model and provides necessary data on production, trade flows, economic data, and emissions, which EPPA aggregates into 16 regions and 21 economic sectors.
In-house vs. outsourced use	Accessibility of the GTAP database within the EPPA model makes in-house use feasible.
Cost of implementation and maintenance	EPPA is a publicly available model that can only be used for educational or research purposes (not for commercial use). MIT does not provide any technical support or maintenance for EPPA, and users must also edit the source code to reflect economic or technological changes.
Examples of use	"Climate Change Policy in Brazil and Mexico: Results from the MIT EPPA Model" (*Energy Economics*, 2016): This paper uses the EPPA model to quantify the monetary costs associated with Brazil and Mexico meeting UN emissions commitments. Also, a CGE model using GTAP data was used in the Indonesia geothermal case study.
Use cases for CIF	(1) Investment plan and project design: can produce ex-ante project benefits and costs to evaluate project plans. (2) Exploration and collaboration with partners: macroeconomic results are understood widely so are effective at communication with local ministries of finance, development banks, or

[4] For details on the benefits of CGE modeling approaches, see the discussion in Section 4. As noted in the Indonesia case study, one challenge of applying CGE models is that investments below a certain size are not detectable. This would typically pose a challenge for CIF investments given the size of those investments compared to national GDP. We addressed this issue by increasing the scale of the investment, and then apportioning the resulting GDP and other macro improvements to the investment level.

Emissions Prediction and Policy Analysis (EPPA)	
	development partners. (3) Understanding tradeoffs between investment opportunities: By quantifying the economic costs associated with different emissions policies, EPPA can be used to better compare different investment strategies. (4) Ex-post evaluation of development impacts from climate finance: as CGEs were applied in the Indonesia case study.
Outputs/Units	The model output of EPPA can vary by specifications. Under the economic specification, outputs include gross output by sector and output supplied to each final demand sector. These outputs can be considered in terms of energy (exajoules), emissions (tons), land use (hectares), population (billions of people), natural resource stocks (exajoules, hectares) and efficiencies (energy produced/energy used). More broadly, EPPA can also produce outputs related to water, land and atmospheric changes (i.e., sea level rise, GHG concentrations, soil and vegetative carbon, net primary productivity, and global mean temperature, among others).

The second activity would entail developing a sectoral modeling framework that would develop more defensible inputs to the macro models—for instance, translating the installed capacity (in MW) of a planned hydropower project into energy generation (in MWh), using modeled streamflow under a range of scenarios. This would encompass tools to evaluate energy investments, as well as a broader suite of investments in agriculture, land use, transportation, and other sectors. **Box 1** describes a framework being jointly developed by IEc and the World Bank's macro team for the Bank's Country Climate and Development Reports, and focusing on resilience and adaptation benefits.

Box 1: Illustration of a Framework to Assess Macroeconomic Benefits

IEc is providing technical assistance to the World Bank in the development of Country Climate and Development Reports (CCDRs) in eight countries. We are using sectoral models to develop "channels of impact" within existing World Bank macro models that are helping to quantify how climate change and lack of investment affect macroeconomic growth. Four categories of channels are currently covered, each of which has several components that are modeled:

1. **Agriculture, energy, and water**. Includes impacts on (a) rainfed and irrigated crop yields, (b) livestock yields, (c) hydropower generation, and (d) human health through water supply and sanitation.
2. **Infrastructure**. Includes impacts on (a) capital due to inland flooding, (b) roads and bridges, and (c) urban areas due to flooding.
3. **Labor supply and productivity**. Includes the effect of rising temperatures on labor productivity through (a) heat and (b) the spread of disease.
4. **Ecosystems and land use**. Includes impacts on (a) human health and ecosystems due to fuelwood harvesting and use for indoor cooking, and (b) linkages between afforestation and reduced inland flooding.

The analytical framework involves both "Business-As-Usual" and "Aspirational Growth" policy scenarios, each under "without adaptation" and "with adaptation" (i.e., a 2x2 scenario grid). Each scenario is run under a range of climate projections from the CMIP6 model ensemble to ensure adaptations/investments are robust to a range of future climate conditions. Data inputs include globally available datasets (e.g., on climate, land use, cropping patterns, livestock density) that are vetted using local sources and planning.

These analyses build on work completed over the past 10 years in more than 15 countries within several World Bank regions (SSA, ECA, EAP, and SA), where we developed "stylized" biophysical and socioeconomic models to produce "channels of impact" that linked into existing CGE models. The purpose of these earlier studies was to understand the macroeconomic benefits of investments aimed at (a) boosting development and (b) enhancing climate resilience.

For an application in Indonesia, see: https://openknowledge.worldbank.org/handle/10986/36727, and in Uganda, see: https://www.mwe.go.ug/library/economic-study-2016-contribution-water-development-and-environment-resources-uganda%E2%80%99s.

CONCLUDING REMARKS

The goal of this section was to develop recommendations on one or more tools that CIF should consider investing in to advance its development impact-related monitoring, evaluation, and learning objectives. Note that few off-the-shelf tools aside from JIM meet all of CIF's objectives of ease of use, readily available global data, analytical defensibility, and ability to address the benefits of a range of investment options. Most tools will require developing some in-house expertise or funding an outside group that provides analytical services. This includes the tools recommended above: LEAP, AquaCrop, and the CGE/sectoral modeling framework.

4. REVIEW OF THE JIM TOOL

JIM is an input-output (I-O) modeling tool that relies on multipliers to estimate the economy-wide effects of an initial change in economic activity. The initial change may involve the construction of a new project or an infusion of funding to a particular sector due to an increase in private sector investment, government spending, or consumer spending, for example. I-O models use data from a variety of sources to map the buying and selling relationships between industries, governments, and households within a region. For example, the model may include a coefficient where for every $200,000 of output from a given industry, one full-time employee is needed to produce that output, and the employee costs $40,000. The strength of I-O models stems from the detailed set of relationships between industries that allow users to quantify the impact of demand changes on particular industry sectors within a region.

However, there are notable limitations to I-O models. First, I-O models rely on fixed functional relationships between inputs and outputs. For instance, based on the formula above, if $1 million of output is produced, five employees would be needed, but in reality, as a company grows, there may be economies of scale or synergies, so only three to four employees may be needed to grow to $1 million in output. I-O models also assume there are no constraints on the supply of raw materials or employees (if more output is desired, materials and employees are always available), and they are static with regard to prices (the price of labor never changes, regardless of the demand for employees). As a result, I-O models are best suited for assessing relatively small, short-term changes in demand. While CIF-supported projects typically involve multi-million-dollar investments, compared with total sector or country output, these investments are generally consistent with the type of small and/or short-term investments that I-O models are suitable to analyze. If, however, the level of investment becomes large enough that changes in prices or the relationships (coefficients) between industries, governments, and households are possible, I-O models will often overestimate the economic impacts, because of the fixed nature of the relationships embedded in such models. Later in this section, we discuss computable general equilibrium (CGE) models as a possible alternative to I-O models for certain types of large-scale portfolio analyses.

The JIM tool looks at the construction and operation phases of particular projects and produces different categories of impacts. According to the JIM documentation, these categories are: direct impacts of the project itself, induced impacts from an increased spending of wages by workers associated with the project and by the workers corresponding with the supply chains, and indirect impacts. While the JIM documentation does not provide a definition of "indirect," based on the model logic, most likely, indirect impacts are impacts on the supply chains, both upstream and downstream, and induced impacts.[5]

Table 6 provides a comparison of JIM with other tools that CIF has recently considered for evaluating development co-benefits of CIF investments. I-JEDI and EFA are frameworks that focus on energy—specifically, renewable energy. I-JEDI produces direct, indirect, and induced jobs (in construction and operation), and direct, indirect, and induced value added (in construction and operation). The EFA tool produces direct jobs (in construction and operation).

Table 6. Comparison of Approaches

	JIM	I-JEDI	EFA
Method	I-O model based on Global Trade Analysis Project (GTAP) dataset	I-O model based on OECD data for five countries: South Africa, Mexico, Zambia, Philippines, and Colombia	Technology-based coefficients
Focus	Economy-wide (65 sectors)	Renewable energy	Renewable energy
Primary outputs	• Jobs (indirect induced) • Value added (direct, indirect induced) • Energy-enabled jobs & value added	• Jobs (direct, indirect induced) • Value added (direct, indirect induced)	• Jobs (direct)
Additional relevant outputs	• GHG emissions • Female employment • Informal sector employment • Supply chain jobs • *Job quality (in development)*	None	None
Base year data	2014	2011, but can be readily updated	Varies (draws from multiple publications from 2009–2014)

SUBSECTOR EMPLOYMENT OUTPUTS

In addition to information on jobs and value added, JIM also generates more granular subsector estimates of employment—for example, for women or informal employment. There is a potential to include a module that will provide information on job quality (e.g., earnings, job security, employability, and gender equality) following a methodology developed by The Good Economy (TGE) for the Good Jobs Rating Model (https://thegoodeconomy.co.uk/services/tools/the-good-jobs-rating). Based on a review of the JIM methodology document, subsector employment figures appear to be calculated based on macro-statistics. For example, to calculate the female share of employment generated by an investment, employment in a sector is multiplied by the share of female employment in a country. While this approach can serve as a reasonable first-order approximation of female employment, it does not account for variations that may exist by sector and/or location. Even if sector-specific data on female employment are available for a given country, they may not be representative of the specific companies

[5] According to the JIM User Guide, *supply chain* impacts are "impacts at the client company/project's suppliers and their suppliers", and *induced* impacts relate to "Impacts associated with the spending of wages earned by employees of the client company/project, its suppliers and their suppliers"

involved in a CIF-supported project, or for the subset of companies that operate within the supply chain affected by CIF investments.

The calculation of informal sector employment relies on a static coefficient derived from the literature. Notably, an important foundational assumption for these figures is that the total output as reported in the GTAP dataset for each country is inclusive of both formal and informal sector employment. While this assumption may seem reasonable, the inclusion of informal employment within GTAP is often missing and/or incomplete. Similar limitations associated with data availability are likely also relevant to efforts to expand JIM to provide additional indicators related to job quality.

Generally, when reporting any subsector employment figures calculated from JIM, it will be important to identify the employment percentages used by JIM for the subject country. This type of transparency will make it easier for stakeholders to understand the uncertainties in these estimates. For investments where there is potential for improving employment for specific subgroups, the IEc team recommends researching the availability of more granular country-, sector- or location-specific employment data. When job quality is of interest, it may be useful to compare job conditions and salaries created by the project with the current job conditions and salaries of other project analogues (e.g., similar companies in the same industry, or companies located in close proximity to the CIF-supported project).

Based on our review, **Table 7** summarizes our confidence in the primary outputs and several other relevant outputs generated by JIM. The tool is strongest in quantifying direct value added, indirect value added, and greenhouse gas (GHG) emissions. We have less confidence in the estimates of indirect, induced jobs, and induced value added, and would consider the outputs for the remaining additional outputs indicative, primarily due to data limitations.

Table 7. Assessment of JIM Outputs

Output	Confidence	Comments on Assumptions/Weaknesses
Primary Outputs		
Jobs (indirect induced)	Low–medium	None noted
Value-Added: direct	Medium–high	None noted
Value-Added: indirect	Medium	None noted
Value-Added: induced	Low–medium	None noted
Additional Relevant		
GHG emissions	Medium	None noted
Female employment	Low	Employment in a sector is multiplied by the share of female employment in a country. While this can provide a reasonable first-order approximation of female employment, it does not account for variations that may exist by sector and/or location.
Informal sector employment	Low	Assumes total output from GTAP is inclusive of both formal and informal sector employment, yet informal employment within GTAP is often missing and/or incomplete
Supply chain jobs	Low	Data limitations are likely to be an issue.
Job quality (in development)	Low	Limitations on data availability are likely to be a challenge in expanding JIM to provide job quality indicators.

RECOMMENDATIONS FOR IMPROVING JIM

Overall, as indicated in Section 2, JIM is a fit-for-purpose tool that meets CIF's objectives for screening-level evaluation of the co-benefits of investments. In terms of priorities for improving the tool, based on a review of the available JIM model documentation, the IEc team recommends focusing near-term resources on first improving the available documentation on sectoral representation and then conducting comparative assessments to test the robustness of the JIM model. While improving gender-specific information and informal sector representation is also important, improvements to JIM in these areas will be more challenging due to data limitations. **Table 8** summarizes the IEc team's recommended priorities for improving the JIM model.

Table 8. Recommendations for JIM Improvements

Subject	Recommendation
Guidance for users on how to assign their investments to GTAP sectors	JIM uses GTAP sectors that are different from International Standard Industrial Classification (ISIC) or GISC (Global Industry Classification) standards. An organizational framework should be provided to users with clear examples how to assign investments to different sectors.
Robustness of JIM results compared to other, more detailed studies.	It would be useful for JIM users to be able to understand the robustness/validity of JIM results, relative to other economic studies or tools. This could be accomplished through a literature review that compares estimates from the literature to the equivalent values (i.e., based on the same inputs as reported in the studies) produced using JIM.
Improving gender specific calculation	Detailed information should be provided to users on the percentages used to estimate the female share of employment by country.
Improving informal sector representation	JIM modelers should check their approach of treating GTAP output as being inclusive of the informal sector.
Considering job quality characteristics	JIM modelers should report their proposed approach of collecting and representing relevant data.
User-friendly interface	User interface could use improvement. Currently it is somewhat confusing, especially when different versions of JIM have different formats for the input and output data.

COMPARATIVE MODEL FOCUS: COMPUTABLE GENERAL EQUILIBRIUM (CGE) MODELS

Using computable general equilibrium models is a step beyond I-O modeling, because CGE models allow behavioral representation of economic agents. People and businesses respond to changes in prices, and capturing the associated behavioral responses can significantly improve the accuracy of analyses of the economic impacts of climate finance investments. CGE models keep the strength of the I-O models while adding numerous important features, such as supply and capacity constraints, a change in production structure coefficients, and accounting for differences by income categories. In general, CGE modeling is more complicated than I-O analyses, so different approaches might be more suitable for a particular task depending on the available time, budget, and expertise.

In a portfolio-level analysis, the primary benefit of a CGE model is its consistent and comprehensive accounting framework, which simultaneously integrates multiple effects of an investment or regulation into the system of resource constraints faced by all agents. CGE models can ensure that changes in demand for commodities and factors are matched by changes in supply elsewhere, that producers' sales revenues flow back to households in payments for inputs and as profits to owners, that households' income receipts must be spent or saved, and that the government budget must balance (at least over the long term). These elements enforce a useful reality check. For example, an additional use of labor in one industry necessarily attracts workers from other pursuits and can result in a bidding up of desired wage rates. CGE models can also incorporate consumers' cross-price elasticities of demand. For example, when a new investment in one commodity lowers its price, consumers may shift spending from substitutes and/or toward product complements. CGE models are able to calculate the effects all in a manner simultaneously consistent with agents' budget and resource constraints. **Box 2** describes another potentially valuable output of CGE models to CIF: estimates of labor migration.

Box 2: Labor Migration

Another useful aspect to consider is incorporation of projections for labor migration. GTAP has evaluated this at a country level (see https://www.gtap.agecon.purdue.edu/models/labor_migration.asp). A challenging, but useful extension of this approach is a labor migration analysis between regions within a particular country. The economics literature increasingly recognizes the importance of migration and its ties with many other aspects of development and policy, and GTAP has developed a database for use in analysis of labor migration issues. Most likely, an I-O approach (used by JIM) would not be suitable for representing migration, because it would require behavioral responses that are not represented in I-O modeling. However, these dynamics can be captured by a CGE approach. Energy transformation may substantially affect particular industries, regions in a country and whole countries, so a better understanding of potential labor migration would be a valuable addition to CIF co-benefits analysis.

Conditions when CGE modeling would be useful

In terms of projects best suited for CGE use, the following conditions might be helpful to consider:

- Whether the analysis should be based on **solid microeconomic foundations:** Economic agents (firms and consumers) respond to price changes, and their responses are driven by behavioral decisions based on cost minimization (profit maximization) and utility (consumption) maximization subject to technology and budget constraints;
- Whether the **behavioral responses** of producers and consumers are important;
- Whether **consistency in terms of budget and resource constraints** is important;
- Whether **impacts on regional, country, and/or global** economic activities are important, or just impacts in a particular project location;
- Whether there is a reason to anticipate **substantial impacts on multiple sectors** of economy;
- Whether **welfare analysis** (change in macroeconomic consumption, change in GDP, etc.) is important;
- Whether consistent representation of **dynamic impacts** (changes over time) is important;
- Whether **data for CGE modeling** (i.e., I-O table or social accounting matrix for a region of interest) are available; and
- Whether **adequate financial resources** for an analysis are available.

Building and maintaining CGE models requires information about inter-industry connections (expressed in monetary terms) and patterns of consumption (in terms of consumption of good distinguished by industry/economic sector) for a particular year. Usually this information comes from I-O tables, social accounting matrices, or established databases, such as the Global Trade Analysis (GTAP) database. CGE developers need information on responsiveness to prices and income levels (i.e., elasticities). Usually, information on elasticities comes from sector-specific or region-specific studies, or from established databases such as GTAP.

Depending on the focus of a CGE analysis, the standard economic specification of a CGE model in monetary terms (capital rents, labor, resource rents, gross output of each sector and output supplied to each final demand sector) can be augmented with accounts in physical terms on energy (exajoules), emissions (tons), land use (hectares), population (billions of people), natural resource endowments (exajoules, hectares) and efficiencies (energy produced/energy used) of advanced technology. These supplemental physical accounts translate economic accounts (in monetary terms) to corresponding estimates of physical depletion and use of natural resources, technical efficiencies of energy conversion processes and against limits of annual availability of renewable resources such as land availability, and the number of people affected to consider health effects.[6]

Description of MIT's EPPA Model

The global tool (called EPPA, which stands for Economic Projection and Policy Analysis) is similar in structure to country-specific tools. EPPA is a multi-region, multi-sector, dynamic general equilibrium model of the world economy, built on the GTAP dataset (the same dataset as in JIM) and additional data for GHG and urban gas emissions, and details of selected economic sectors and particular low-carbon technologies. Provisions are made for analysis of uncertainty in key human influences, such as the growth of population and economic activity and the pace and direction of technical advances. It is designed to develop projections of economic growth, energy transitions and anthropogenic emissions of GHGs and air pollutants. The model projects economic variables and emissions of GHGs and other air pollutants from combustion of carbon-based fuels, industrial processes, waste handling, agricultural activities and land use change.

The MIT-EPPA model represents interactions among three types of agents: households, firms, and the government. Households own the primary factors of production (e.g., labor, capital and natural resources) which they rent to firms, using this income to purchase goods and services. In each sector of the model, firms produce commodities by combining factors of production and intermediate inputs (i.e., goods produced by other sectors). The government sets policies and collects tax revenue, which it spends on providing goods and services for households and on transfer payments to households. In addition, a carbon price is imposed on all GHG emissions, with the revenues redistributed back to households via lump-sum transfers. Equilibrium is obtained through a series of markets (for both factors of production and goods and services) that determine prices, so that supply equals demand.

The EPPA model chooses the least-cost production opportunities based on market clearance conditions (supply must equal demand), normal profit conditions (the cost of inputs should not exceed the price of the output), and income balance conditions (expenditures must equal income, accounting for savings, subsidies and taxes). Growth in population and economic activity (as measured by gross domestic product, GDP) are the key drivers of changes over time.

[6] An example of CGE modeling at the global and country-specific levels is an activity of the MIT Joint Program on the Science and policy of Global Change that successfully applies for policy studies its global tool (https://globalchange.mit.edu/research/research-tools/human-system-model) and country-specific tools (https://globalchange.mit.edu/research/research-projects/pathways-paris).

Comparison between JIM and CGE outputs: Case study in Indonesia

As noted above, one of the case studies included in the wider evaluation by IEc used CGE modeling to evaluate the benefits of CIF-enabled investments in geothermal energy in Indonesia. Here we compare JIM and CGE outputs for this set of investments. Key information about the geothermal projects considered is provided in **Table 9**. In total, the projects cost $455 million and have an installed capacity of 2,120 MW.

Table 9. Characteristics of Geothermal Projects

Project Name	Start Year	Cost (million USD)	Installed Capacity (MW)
Geothermal Clean Energy Investment Project (GCEIP)	2018	$125	150
Geothermal Energy Upstream Development Project (GEUDP)	2025	$50	65
Geothermal Resource Risk Mitigation (GREM)	2029	$75	1,000
Geothermal Power Generation Program (GPGP)	2024	$35	55
Geothermal Electricity Finance Program (GEFP)	2022	$20	250
Private Sector Geothermal Project (PSGP)	2022	$150	600
Total		**$455**	**2,120**

Running these geothermal projects through JIM for Indonesia produces the benefits in **Table 10**. For comparison, **Table 11** shows the CGE outputs for the same volume of power generation.

Table 10. JIM Energy-Enabled Outputs for Geothermal Projects in Indonesia

Project Name	Employment (# jobs)			GHG Emissions Avoided (tCO_2e)	Total Value Added (million USD/year)			
	Formal	Informal	Total		Savings	Taxes	Wages	Total
GCEIP	2,477	7,323	9,800	58,752	$34.3	$9.6	$31.1	$75.0
GEUDP	1,073	3,173	4,246	25,459	$14.9	$4.2	$13.5	$32.5
GREM	16,513	48,818	65,331	391,677	$229.0	$64.0	$207.2	$500.2
GPGP	908	2,685	3,593	21,542	$12.6	$3.5	$11.4	$27.5
GEFP	4,128	12,204	16,333	97,919	$57.2	$16.0	$51.8	$125.1
PSGP	9,908	29,291	39,198	235,006	$137.4	$38.4	$124.3	$300.1
Total	**35,007**	**103,494**	**138,501**	**830,356**	**$485.4**	**$135.7**	**$439.3**	**$1,060**

Table 11. CGE Outputs for 2,120 MW of Geothermal Projects in Indonesia

Formal Employment (# jobs)	GHG Emissions Avoided (tCO_2e)	Net Economy-Wide Impacts without Additional Benefits, (million USD)	Additional Impacts of the Project	
			Health Benefits, (million USD)	Human Capital if Project Expands Access to Electricity (million USD)
29,001	1,332,344	$107	$2,204	$27,574

Note: Results assume a levelized cost of electricity for geothermal of US$25/MWh. At $50/MWh, the economy-wide impacts of the projects are negative relative to the cheapest alternative source. "Human capital" refers to added skills based on education and other professional development.

Comparatively speaking, we observe the following:

- **Employment:** JIM shows the investments enable a total of 138,510 jobs, of which 35,007 are formal employment. CGE shows a similar level of formal employment (29,001 jobs), but cannot estimate informal employment, which appears to be significant.
- **GHG emissions:** JIM estimates that the projects avoid producing 830,356 tCO_2e each year, and CGE estimates economy-wide emission reduction of 1.3 million tCO_2e. This difference can be attributed to economy-wide impacts (including the impact on other power generation sources) captured by a CGE approach.
- **Economic impacts:** JIM estimates a total value added of $1.06 billion per year, whereas CGE estimates economy-wide impacts of only $107 million annually, about 10 percent of the JIM estimate. This is primarily because the CGE estimates net effects, comparing the investments with an economy where the same generation capacity is still added, but with the next-cheapest (non-geothermal) alternative. The total value added estimated by JIM provides a gross variable that does not directly comparable to a change in GDP or an economy-wide welfare impact.
- The CGE model also monetizes the health and electrification benefits of the projects over a 30-year period, which are $2.2 billion and $27.6 billion, respectively.

In summary, it is appropriate to apply JIM to portfolios of projects where benefits estimates do not need to include the behavioral responses of producers and consumers. For comprehensive assessments of the impacts of the projects on the economy, the CGE tool is suggested, because it is based on a well-established economic approach that combines production side of the projects, including resource and capacity constraints, with behavioral responses of economic agents on both the supply and demand sides.

APPENDIX A: REVIEW OF MODELING APPROACHES

Table A-1. Model Review for Category 1: Improved Air Quality and Resulting Health Benefits

GEOS-Chem	
Description	Overall, GEOS-Chem models atmospheric composition/chemistry at various scales. Offline, it can be used as a chemical transport model with capabilities to model atmospheric chemistry/composition using meteorological data from NASA's Goddard Earth Observing System. Online, GEOS-Chem can be used as a weather and climate model to consider composition of 1-D atmospheric columns. There are different interfaces: GC Classic (oldest and most common version of model; simulations run on one computer at a time); GEOS-Chem High Performance (allows for higher resolution of model); and GEOS-Chem within another parent model (GEOS-Chem in CEOS-5,CESM-GEOS-Chem, Weather Research and Forecasting GEOS-Chem]).
URL	https://geos-chem.seas.harvard.edu/
Complexity	Minimum system requirement: **Hardware requirements:** (1) Computer requirements: A Unix-based computer system or an Amazon Web Services Cloud account (2) Memory requirements: A computer with enough memory to run GEOS-Chem at various resolutions; **Software requirements:** (1) C and C++ compliers are needed for GEOS-Chem Classic to translate Fortran programming language; **Additional required software**: (1) Git (needed to download GEOS-Chem source code), (2) CMake (executes GEOS-Chem source code), (3) GNU Make (not required for most recent version of GEOS-Chem, but necessary to download some external libraries), (4) netCDF (a file format for storing weather- and climate-related data [i.e., temperature, humidity, pressure, wind speed etc.]; GEOS-Chem input and output data files are in netCDF file format); **Required source code and data:** Access to the GEOS-Chem Classic repository (contains codebase and HEMCO [Harmonized Emission Component codebase], GEOS-Chem shared data directories (contains meteorology and emission data that acts as input), Restart files (Files that simulate initial conditions needed to run GEOS-Chem simulations).
In-house vs. outsourced use	GEOS-Chem is a community-based, user-owned platform, but knowledge of atmospheric chemistry is required to operate the tool. Thus, it may not have consequential in-house use, depending on the background of the user.
Cost of implementation and maintenance	GEOS-Chem is an open-source and community-based model. Users can report any issues with the model to support staff based at Harvard and Washington University.
Use cases for CIF	(1) Investment Plans and project design: GEOS-Chem could provide environmental context regarding air quality and potential risk exposure. This context could help guide investment plans. (3) Understanding tradeoffs between investment opportunities: the tool can consider a range of interventions. (4) Ex-post evaluation of development impacts from climate finance: modeling of atmospheric chemistry to evaluate an already-built project.
Example of use	"Transboundary health impacts of transported global air pollution and international trade" (*Nature,* 2017): Paper analyzes premature mortality due to $PM_{2.5}$ pollution and utilizes GEOS-Chem to consider regional pollution and $PM_{2.5}$ exposure. More comprehensive list of publications using GEOS-Chem: (https://scholar.google.com/citations?user=ho-sNj4AAAAJ)
Output/Units	Depending on model specifications, GEOS-Chem can produce outputs measuring surface and vertical air quality. In the model, PM exposure is measured in $\mu g/m^3$.

Low Emissions Analysis Platform (LEAP)	
Description	Developed by the Stockholm Environment Institute, LEAP is a scenario-based modeling tool primarily used for energy policy analysis and climate change mitigation assessments. Overall, LEAP can act as a database for storing energy information, a forecasting tool to consider energy supply and demand, and a policy tool to consider the economic and environmental effects of various energy programs and investments. As an integrated modeling tool, LEAP can be used to analyze energy consumption, production, and resource use across different sectors in the economy, while also considering demographic and macroeconomic data. LEAP can be used at the city and national scale for energy planning, low-emission development strategies (LEDS), and national communications (i.e., reporting to the UNFCCC).
URL	https://leap.sei.org/default.asp?action=home
Complexity	LEAP has been designed to be accessible for decision-makers and those involved in energy and climate policy. There are low data requirements to get started, so LEAP can be used in developing countries, which may have low-quality data. However, the model can be made more sophisticated based on available data. The model includes an API that allows it to interface with other tools (i.e., Water Evaluation and Planning System [WEAP, used for integrated water resource planning], Integrated Benefits Calculator [IBM, used to examine health and agriculture implications of different climate scenarios]). **Data requirements** for LEAP's demand analysis include: demographic data, macroeconomic data, and energy data (national balances, mitigation assessments, energy policy, energy prices, energy supply, energy extraction, energy sector emissions, GHG sinks, and fuel characteristics). **Hardware and software requirements:** LEAP can operate on any PC; an internet connection is not required.
In-house vs. outsourced use	LEAP is an open-source tool designed to be accessible for individuals with limited modeling background, thus, in-house use seems very possible.
Cost of implementation and maintenance	The LEAP tool and its training materials are free to academics, governments, and NGOs based in low- and middle-income countries, in addition to all students. For businesses and utilities, LEAP must be accessed through its licensing agreements, the costs of which range from US$500 to $3,000.
Use cases for CIF	(1) Investment Plans and project design: LEAP could help guide a country's energy investments by modeling economic and environmental impacts while also considering the demographic and macroeconomic context of a country. Also, through its ability to forecast energy demand, the LEAP model could be useful in guiding investment plans and project design (2) Exploration and collaboration with partners: LEAP is designed to be an accessible tool for those who may not have a hard science background. This element promotes use by different stakeholders and could promote collaboration. (3) Understanding trade-offs between investment opportunities: the LEAP tool allows for consideration of a range of investment options. (4) Ex-post evaluation of development impacts from climate finance: similar application to how LEAP was used in the Thailand case study.
Example of use	"Energy Efficiency Plan Benefits in Ecuador: Long-range Energy Alternative Planning Model" (*International Journal of Energy Economics and Policy*, 2018). Paper utilizes LEAP to forecast annual energy demand until 2035 in Ecuador.
Output/Units	Depending on model specifications, LEAP can have numerous outputs. Outputs related to energy supply and demand metrics can be displayed as energy balance tables. These tables can be viewed for various fuels, years, scenarios, regions, and subsectors. Demand and supply metrics can be displayed in almost any unit of measurement and in various numeric formats (i.e., absolute values, growth rates, percentage shares, etc.).

Environmental Benefits Mapping and Analysis Program (BenMap)	
Description	Developed by the EPA, BenMap is a program used to quantify the health and economic impacts of changes in air quality—specifically, fine particles and ground-level ozone. Health impacts are quantified through a health impact function that considers (1) modeled or monitored changes in air quality, (2) population, (3) baseline incidence rates, and (4) an effect estimate. Economic values are calculated through (1) costs of illness metrics (i.e., expenses incurred as a result of air pollution illness), and (2) willingness to pay metrics (i.e., WTP to avoid air pollution-related illness).
URL	https://www.epa.gov/benmap
Complexity	**Data requirements:** The BenMap tool includes data on grid definitions, pollutants (Ozone and PM 2.5), monitoring, incidence and prevalence rates, population, health impact functions, inflation rates, socio-economic variables and valuation functions that are needed to quantify health and economic effects. Specific Air Quality System data (AQS) can also be downloaded and imported for use in BenMap. **Computer requirements:** BenMap can be run on a Windows 7 machine or subsequent version of Windows. BenMap also requires a computer with 32 or 64 bit operating system, Adobe Acrobat Reader, Microsoft Excel (or similar spreadsheet program), Microsoft .NET framework, at least 4 gigabytes of RAM, an Intel or compatible processor, and available disk space for installation.
In-house vs. outsourced use	BenMap is designed to be an accessible tool through its provision of all necessary input data. Thus, in-house use of this tool seems very possible.
Cost of implementation and maintenance	BenMap is a free and open source tool. The source code can be obtained through the EPA or through GitHub
Use cases for CIF	(1) Investment Plans and project design: By assessing potential health impacts in different areas, BenMap provides context on relative environmental health risks, and therefore could help prioritize investment strategies. (3) Understanding tradeoffs between investment opportunities: Again, by assessing environmental health risks by area, and through its valuation capabilities, BenMap could help understand trade-offs between different investment sites. (i.e., when deciding between two investment strategies, BenMap's valuation of health impacts serve as the benefits to an associated investment strategy [because the benefit of the investment would in part be the health impacts avoided]). (4) Ex-post evaluation of development impacts from climate finance: similar application to how LEAP was used in the Thailand case study.
Example of use	"Climate change and health costs of air emissions from biofuels and gasoline" (*PNAS*, 2008): Paper utilizes BenMap to quantify health impacts associated with increased $PM_{2.5}$ levels from gasoline, corn ethanol, and cellulosic ethanol in the U.S. More comprehensive list of BenMap use: https://www.epa.gov/benmap/benmap-ce-applications-articles-and-presentations.
Output/Units	BenMap allows users to calculate (1) changes in air quality between baseline and scenario conditions (changes in ozone measured in ppb and changes in particulate matter measured in $\mu g/m^3$), (2) changes in population exposure (measured in number of people), (3) changes in health effect incidences (captured by beta variable which represents percent change in adverse health impact per unit of population), and (4) monetary benefits of health effect incidence changes (measured in monetary terms).
Air Q+	
Description	Developed by the World Health Organization Regional Office for Europe, the AirQ+ tool allows users to quantify the effect of short-term changes in air pollution and long-term exposures to air pollution. Specifically, AirQ+ can be used to calculate: attributable proportion of cases, number of attributable cases, number of attributable cases per 100,000 people, proportion of cases in each category of air pollutant concentration, distribution by air pollutant concentration, and year of life lost. AirQ+ can be used for $PM_{2.5}$ and PM_{10}, nitrogen dioxide, ozone, and black carbon.
URL	https://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/airq-software-tool-for-health-risk-assessment-of-air-pollution
Complexity	**Data requirements:** Users must provide data on air quality (i.e., frequency of days with x levels of pollution), population (i.e., adults over 35), and health (i.e., baseline rate of incidence) **Computer requirements:** AirQ+ has been tested to run on Windows, Linux, and Macintosh operating systems. These systems must also have Java installed.

In-house vs. outsourced use	Compared with similar tools, such as BenMap, in-house use is less likely due to increased data requirements.
Cost of implementation and maintenance	AirQ+ is a free software tool that can be downloaded through the WHO website.
Use cases for CIF	(1) Investment Plans and project design: Similarl to BenMap, this tool provides context on relative environmental health risks, and therefore could help prioritize investment strategies. (3) Understanding tradeoffs between investment opportunities: the tool can consider a range of interventions.
Example of use	"Quantifying the Public Health Benefits of Reducing Air Pollution: Critically Assessing the Features and Capabilities of WHO's AirQ+ and U.S. EPA's Environmental Benefits Mapping and Analysis Program–Community Edition (BenMap–CE)" (*Atmosphere*, 2020): Paper utilizes AirQ+ to assess health benefits of decreased air pollution.
Output/Units	Depending on the time period and the air pollution considered, Air Q+ can allow users to calculate attributable proportion of cases, number of attributable cases, number of attributable cases per 100,000 people, proportion of cases in each category of air pollutant concentration, distribution by air pollutant concentration, and years of life lost.
CO-Benefits Risk Assessment (COBRA)	
Description	Developed by the Abt Associates and now managed by the EPA, COBRA is a screening model and mapping tool that quantifies the health impacts of changes in ambient particulate matter air pollution. Within the model the user defines changes in emissions and COBRA computes subsequent health effects and monetizes these effects. Specifically, health outcomes considered include adult and infant mortality, nonfatal heart attacks, respiratory related and cardiovascular hospitalization, acute bronchitis, respiratory symptoms, asthma-related emergency room visits, asthma exacerbation, restricted activity days, and workdays lost to illness.
URL	https://www.epa.gov/cobra
Complexity	**Data requirement:** Cobra screening model contains all data needed to run (i.e., emissions inventories, an air quality model, health impact equations, and economic valuations). The user must only specify the change in concentration it would like COBRA to model. **Computer Requirements**: COBRA can be run on any computer with 6 GB of free space, 6+ GB of RAM, i5 processor, and Windows 7 or newer). COBRA can be downloaded to a desktop or accessed online.
In-house vs. outsourced use	The model can be used by those without a background in air quality, environmental health or economic valuation. Also, by providing all necessary input data, in-house use seems possible.
Cost of Implementation and maintenance	COBRA is a free tool that can be downloaded onto one's desktop or accessed via the internet.
Use cases for CIF	(1) Investment Plans and project design: Similarl to other strategies, this tool provides context on relative environmental health risks, and therefore could help prioritize investment strategies. (3) Understanding tradeoffs between investment opportunities: Similar to BenMap, by assessing environmental health risks by area, and its valuation capabilities, COBRA could help understand trade-offs between different investment sites. (i.e., when deciding between two investment strategies, COBRA's valuation of health impacts serve as the benefits to an associated investment strategy [because the benefit of the investment would in part be the health impacts avoided]). (4) Ex-post evaluation of development impacts from climate finance: similar application to how LEAP was used in the Thailand case study.
Example of use	Health Note on the New Jersey Department of Environmental Protection proposed regulation: Advanced Clean Trucks Program and Fleet Reporting Requirements (2021): Paper utilized COBRA to quantify the health benefits of a New Jersey rule that would reduce $PM_{2.5}$ emissions from vehicles; More comprehensive list of publications using COBRA: https://www.epa.gov/system/files/documents/2021-10/cobra-publications_9.14.21.pdf.
Output/Units	COBRA outputs include the annual number of adverse health impacts avoided specifically for mortality, asthma exacerbations, heart attacks, hospital admissions, acute bronchitis, respiratory symptoms asthma ER visits, minor restricted activity days, and workdays lost. COBRA can also monetize these avoided health impacts and present them in a monetary unit.

FAst Scenario Screening Tool (TM5-FASST)	
Description	Developed by European Commission Joint Research Center in Italy, the TM5-FASST tool is a global air quality source receptor model that enables users to quantify how air pollutant emissions impact human health outcomes and crop yields. The model allows the user to choose from emission scenarios existing within the model or create specific emission scenarios. These scenarios are compared with a baseline scenario of emissions to quantify impacts.
URL	https://tm5-fasst.jrc.ec.europa.eu/
Complexity	Complexity of model is unclear due to limited available information online.
In-house vs. outsourced use	Relative in-house vs. outsourced use of tool is difficult to determine given limited information on tool.
Cost of implementation and maintenance	The cost of this tool is unclear. Literature suggests this is a widely used tool. It seems like the user must register through the European Commission's website to have access to the model.
Use cases for CIF	(1) Investment Plans and project design: Similar to other strategies, this tool provides context on relative environmental health risks, and therefore could help prioritize investment strategies. (3) Understanding tradeoffs between investment opportunities: this tool can also consider a range of interventions.
Example of use	Health co-benefits from air pollution and mitigation costs of the Paris Agreement: a modelling study (The Lancet Planetary Health 2018): Paper utilized TM5-FASST to estimate premature deaths and morbidity associated with PM and ozone.
Output/Units	Health impacts are quantified as (1) the annual number of air-quality related premature deaths from PM 2.5 and ozone, and (2) exposure to $PM^{2.5}$ and ozone. These are measured in $\mu g/m^3$ and ppb, respectively. Impacts to crops are quantified through the linear relative yield loss function that the model produces.

Table A-2. Model Review for Category 2: Increased Climate Resilience in Agriculture

Decision Support System for Agrotechnology Transfer (DSSAT)	
Description	DSSAT is a software program that includes crop simulation models (CSM) for over 42 crops. DSSAT can be used to analyze how changes in soil-plant-atmosphere dynamics impact crop growth, development, and yields over multiple years. Specifically, DSSAT can be used to consider how changes in farm management strategies, climate variability, plant breeding, water use, soil conditions, greenhouse gas concentrations, impact crops. The DSSAT model can be run with observed or experimental data to consider various multi-year outcomes.
URL	https://dssat.net/
Complexity	**Data requirements:** Minimum data requirements to run DSSAT include: site weather data (latitude and longitude of weather station, daily solar radiation, daily max. and min. temperatures, daily precipitation), soil data (soil classification, surface slope, color, permeability, drainage class), management data (planting data, planting density, row spacing, planting depth, crop variety, irrigation and fertilizer practices), and experimental data (crop growth, soil, water, and fertility data). The DSSAT website provides links to crop, soil, and weather data sources users can utilize for model. However, this data must be reformatted for use in DSSAT.
In-house vs. outsourced use	Compared with other models, in-house use of DSSAT may be less feasible due to data requirements and overall model complexity.
Cost of implementation and maintenance	DSSAT is a free and open-source software. Users must request to download DSSAT by registering through the DSSAT website.
Use cases for CIF	(1) Investment plan and project design: By simulating crop growth, development, and yields as a function of different conditions, DSSAT can be helpful in identifying crops most vulnerable to changing environmental conditions (e.g., climate change). By identifying these crops, investments can be targeted towards farming areas that will be most impacted. (2) Exploration and collaboration with partners: The DSSAT model considers how environmental changes at local and global scales will impact crops (i.e., the model considers how farming management impacts crops and also how global GHG emissions impact crops). In doing so, the DSSAT model considers how decisions by local and global actors impact crops, and thus can be used to promote collaboration with different stakeholders. (3) Understanding tradeoffs between investment opportunities: various investments can be considered to enhance crop yields. (4) Ex-post evaluation of development impacts from climate finance: much as a crop yield model was employed in the Bangladesh case study.
Example of use	"Assessment of the effect of climate change on boro rice production in Bangladesh using DSSAT model" (*Journal of Civil Engineering*, 2010): Paper utilized DSSAT to determine the impact of climate change on boro rice yields in Bangladesh.
Output/Units	Depending on model specifications, DSSAT can have numerous biophysical outputs related to crop growth, development, and yield some of which include harvest date, harvested yield (kg dm/ha) and nitrogen uptake (kg/ha), among others.
AquaCrop	
Description	Developed by the FAO, AquaCrop is a crop-water productivity model that analyzes the impact of changing water supply on the yields of herbaceous crops. In the model, crop production is simulated by considering the development of green canopy cover, crop transpiration, and above-ground biomass in response to changing water supply. As such, the model considers interactions that influence water availability to crops such as soil plant interactions, management practices, (i.e., irrigation, weed management), and weather conditions. There is also a MATLAB version of the tool available through the University of Nebraska that allows for much faster processing, when large geographic areas or numerous scenario runs are needed.
URL	https://www.fao.org/aquacrop
Complexity	**Data requirements:** Running the AquaCrop model requires information on weather conditions, crop conditions, management conditions (i.e., field management, irrigation management), and soil conditions (i.e., soil profile and groundwater conditions)**.** AquaCrop contains data on mean annual atmospheric carbon dioxide and tools to compute evapotranspiration. However, other data requirements must be inputted by the user. These data requirements include

	daily climatology, water holding capacity, and other inputs that would benefit from an understanding of R, Python, MATLAB, or another data-processing programming tool.
In-house vs. outsourced use	AquaCrop was designed to be used by a range of practitioners outside of the scientific community, and thus assumes a simplified relationship between biomass production and crop transpiration, which ultimately requires less data inputs compared to other models used in the scientific community. Accessibility of some data components within the model makes in-house use of AquaCrop seem more feasible compared to DSSAT.
Cost of Implementation and maintenance	The AquaCrop Windows program can be downloaded through the FAO website for free. Users must provide their contact information to FAO when submitting a download request.
Use cases for CIF	(1) Investment plan and project design: By simulating crop yields as a function of different water supply conditions, AquaCrop can be helpful in identifying crops most vulnerable to changing environmental conditions. By identifying these crops, water management investments can be targeted towards farming areas that will be most impacted. (2) Exploration and collaboration with partners: AquaCrop results are easy to communicate and understand. As noted above, it is not the most user-friendly tool but very powerful once learned. (3) Understanding trade-offs between investment opportunities: AquaCrop allows for evaluation of various interventions to improve yields and thus food security. (4) Ex-post evaluation of development impacts from climate finance: much as a crop yield model was employed in the Bangladesh case study.
Example of use	World Bank. 2013. Looking Beyond the Horizon: How Climate Change Impacts and Adaptation Responses Will Reshape Agriculture in Eastern Europe and Central Asia. https://openknowledge.worldbank.org/handle/10986/13119?show=full
Output/Units	The main model output from AQUACROP is dry yield formation measured in tons/ha, and irrigation water demand, measured in mm. There are also several other secondary outputs including, for instance, volume of fertilizer application.
Environmental Policy Integrated Climate (EPIC) Model	
Description	Developed in partnership by Texas A&M University AgriLife Research, the USDA Agriculture Research Service, and the USDA Natural Resources Conservation Service, EPIC is a cropping systems model (CSM) that can be used to consider: (1) the impacts of soil erosion on productivity and (2) how management decisions can impact soil, water, nutrient, and/or pesticides conditions, and how these changes then impact soil loss, water quality and yields for areas with homogenous soils and management. The model operates on a daily time step and can be used for long-term simulations up to 4,000 years.
URL	https://epicapex.tamu.edu/software/
Complexity	**Data requirements:** The model contains data on soil, weather, tillage, and crop conditions saved as (.dat). Users must then specify the time period, site conditions, soil conditions, field operation schedules (i.e., crop rotation, tillage) weather conditions, climate conditions within the model simulation.
In-house vs. outsourced use	A majority of data inputs required to run EPIC are built within the model, making in-house use seem feasible.
Cost of implementation and maintenance	The use of the EPIC model is reserved for those conducting scientific research and is not intended for commercial use. Users can download the model for free online through the EPIC website.
Use cases for CIF	(1) Investment plan and project design: Alike DSSAT and AquaCrop, by considering how crop yields may change in response to environmental changes, EPIC can be used to identify sites in which crops are vulnerable to potential environmental changes and thus help promote more targeted investment strategy to mitigate or reduce impacts. (3) Understanding tradeoffs between investment opportunities: various investments can be considered to enhance crop yields. (4) Ex-post evaluation of development impacts from climate finance: much as a crop yield model was employed in the Bangladesh case study.
Ex. of Use	"A method for estimating the direct and climatic effect of rising atmospheric carbon dioxide on growth and yield of crops: Part I-Modification of the EPIC model for climate change analysis" (*Agricultural Systems,* 1992): This paper utilized the EPIC model to assess how increases in carbon dioxide concentrations would impact corn, what, and soybean yields.

Output/Units	Depending on model specifications, EPIC can provide numerous outputs related to biomass (measured in T/ha), soil characteristics (i.e., % sand, silt, clay, rock), operational costs (i.e., cost of tillage operation measured in $/ha), yield (measured in T/ha), growth (i.e., root weight measured in T/ha), and hydrology (i.e., runoff measured in mm) among others. These outputs are offered at various time increments including daily, monthly, and annually.
Water Evaluation And Planning (WEAP)	
Description	Developed by the Stockholm Environment Institute, WEAP is a software program that can be used for water resource management and planning. Specifically, WEAP can serve as: (1) a database to store information of water demand and supply and (2) a scenario generation tool to simulate different water conditions (i.e., runoff, storage, pollution, treatment, demand, supply), and (3) a policy analysis tool to evaluate water management strategies.
URL	https://www.weap21.org/
Complexity	**Data requirements:** Information from the WEAP website suggests the following data are useful for modeling (though not every type of data is needed for every analysis): (1) schematic maps of area for analysis; this includes GIS layers in shapefiles; (2) demand data: data on water demand by sector (i.e., withdrawals, consumption, loss, reuse, etc.); (3) hydrology data; (4) groundwater data; (5) reservoir data; (6) supply source data (i.e., data on water transfers or desalination); (7) water loss data; (8) pollutant data (i.e., pollutant loads contributed); (9) wastewater treatment data; (10) water quality data; (11) economic data (i.e., water costs, infrastructure costs).
In-house vs. outsourced use	Similar to LEAP, WEAP is designed to be easy to use tool, with a simplified interface and on-screen guidance features. However, depending on data availability, use of WEAP might be limited. Data can be imported into WEAP in (.csv) and (.xml) formats.
Cost of implementation and maintenance	Use of WEAP by nonprofit, government, or academic organizations based developing countries is free. These users must apply for a license through the WEAP website. Other two-year non-consulting licenses based in industrialized countries have licensing fees ranging from $300-$4,000 USD. To obtain a consulting license users must reach out to WEAP via email. The cost of a consulting licenses is unclear.
Use cases for CIF	(1) Investment Plans and project design: Through its ability to forecast water demand and supply the WEAP model could be useful in guiding investment plans and project design. (2) Exploration and collaboration with partners: WEAP is designed to be an accessible tool which ultimately can promote the use of WEAP by different stakeholders. (3) Understanding trade-offs between investment opportunities: Through its ability to evaluate different water management strategies, WEAP could be helpful in understanding the benefits associated with different investments. (4) Ex-post evaluation of development impacts from climate finance: water systems tools can be used to model the performance of already-built irrigation systems based on observed climate and runoff data.
Example of use	"Assessment of Water Supply-Demand Using Water Evaluation and Planning (WEAP) Model for Ur River Watershed, Madhya Pradesh, India" (The Institution of Engineers (India) 2018): This paper utilizes the WEAP-MABIA model to consider the agricultural water demands along the Ur River.
Output/Units	Depending on model specifications WEAP can quantify numerous outputs related to water resource management including water demand, supply requirement, supply delivered, unmet demand, and demand site inflows and outflows, among others. Outputs can be produced at various time steps including monthly and annually. The user also can define output units, though default units are millions of cubic meters.
Agricultural Production Systems Simulator (APSIM)	
Description	Developed by the Agricultural Production Systems Research Unit in Australia, the APSIM is a crop model that can be used to analyze how biophysical processes in farming systems impact economic and ecological outcomes. Overall, APSIM can be used to analyze how changes in climate, soil conditions, plant genotype, and management practices influence crop production.
URL	https://www.apsim.info/
Complexity	**Data requirements:** Users must input data into APSIM. This includes experimental data, weather data, soil data, and validation data. **Hardware requirements:** APSIM is designed to run on a PC with at least 2 GB of RAM. **Software requirements:** A computer with a 64-bit version of Microsoft Vista, Windows 7, Windows 8, Windows 10, Linux, or macOS.
In-house vs. outsourced use	Depending on data availability, in-house use of APSIM may be limited.

Cost of implementation and maintenance	Users must register through the APSIM website and apply for a: (1) non-commercial research and development license or a (2) commercial license. For non-commercial use access to APSIM is free. For commercial use, licensing fees are tiered to the revenue of the licensing business and range from $A 3,000 to $A 25,000.
Use cases for CIF	(1) Investment plan and project design: Alike DSSAT, AquaCrop, and EPIC, by considering how crop yields may change in response to environmental changes, APSIM can be used to identify crops that are vulnerable to potential environmental changes and thus help promote more targeted investment strategy to mitigate or reduce impacts to these crops. (3) Understanding trade-offs between investment opportunities: APSIM allows users to compare different simulations to understand relative impacts to crops. This feature could enable users to understand relative tradeoffs between different farming practices, policies, and investments. (4) Ex-post evaluation of development impacts from climate finance: much as a crop yield model was employed in the Bangladesh case study.
Example of use	"Quantification of the Impact of Temperature, CO_2, and Rainfall Changes on Swedish Annual Crops Production Using the APSIM Model" (Frontiers in Sustainable Food Systems 2021): This paper utilized the APSIM model to quantify how projected changes in temperatures and carbon dioxide concentrations might impact barley, maize, oat, and wheat productivity in Sweden.
Output/Units	The main output from APSIM is yield measured in kg/ha. APSIM also allows users to consider other biophysical processes of crops and the impacts of management practices (i.e., water runoff, crop nitrogen, and canopy cover, among others).
CropSyst	
Description	Developed by faculty at Washington State and Pennsylvania State University. CropSyst is a multi-year crop simulation model that simulates the soil water budget, crop canopy, root growth, yield, and residue production (among other crop characteristics) by considering changes in water, nitrogen, light, and temperature. The model also considers different management options related to crop rotation, irrigation, fertilizer use, and tillage, among others.
URL	http://bioearth.wsu.edu/cropsyst_model.html
Complexity	**Data requirements:** Data on weather, soil, crop, and management conditions are required to run the CropSyst model. The simulation parameter editor within the model enables users to create different simulations based off a database of weather, soil, crop, and management information built into CropSyst. Additionally, the ClimGen weather generation program built into CroSyst can provide long-term weather data for locations that might not have this data.
In-house vs. outsourced use	Information from FAO suggests that this model is best designed for those with a technical or modeling background, therefore in-house use of CropSyst may be dependent on a user's ability to understand concepts underlying model.
Cost of Implementation and maintenance	CropSyst is an open-source tool that can be downloaded for free online.
Use cases for CIF	(1) Investment plan and project design: Like DSSAT, AquaCrop, EPIC, and APSIM by considering how crop yields may change in response to environmental changes, CropSyst can be used to identify crops that are vulnerable to potential environmental changes and thus help promote more targeted investment strategy to mitigate or reduce impacts to crops. (3) Understanding tradeoffs between investment opportunities: various investments can be considered to enhance crop yields. (4) Ex-post evaluation of development impacts from climate finance: much as a crop yield model was employed in the Bangladesh case study.
Example of use	"Evaluating CropSyst Simulations of Wheat Management in a Wheat-Fallow Region of the US Pacific Northwest" (Agricultural Systems 1998): This paper utilizes the CropSyst model to determine the impact different tillage and residue management practices on wheat yields and evapotranspiration.
Output/Units	The primary model output from CropSyst is yield measured in kg/m^2. CropSyst can produce outputs related to the soil water budget (i.e., canopy, runoff, infiltration, soil evaporation, and transpiration), the nitrogen budget (i.e., nitrogen transport, leaching, and uptake), and crop growth (i.e., aboveground root biomass, leaf area, and root depth), among other biophysical processes.
HERMES	

Description	Developed by the Leibniz-Center for Agricultural Landscape Research (ZALF), HERMES simulates crop growth and nitrogen demand by considering evapotranspiration, water transport, nitrate transport, biomass development, among other plant-soil-atmosphere interactions.
URL	https://www.zalf.de/en/forschung_lehre/software_downloads/Pages/default.aspx
Complexity	**Data requirements:** The direct data requirements needed to run the HERMES model are unclear. Additionally, it is unclear what data might be built into the model versus what data the user is responsible for gathering.
In-house vs. outsourced use	Relative in-house vs. outsourced use of tool is difficult to determine given limited information on tool
Cost of Implementation and maintenance	HERMES is an open-source program that can be downloaded for free from the ZALF website. Maintenance costs associated with the program are unclear.
Use cases for CIF	(1) Investment plan and project design: Alike DSSAT, AquaCrop, EPIC, APSIM, and CropSyst, by considering how crop yields may change in response to environmental changes, HERMES can be used to identify crops that are vulnerable to potential external changes and thus help promote more targeted investment strategy to mitigate or reduce negative impacts to crops. (3) Understanding tradeoffs between investment opportunities: various investments can be considered to enhance crop yields. (4) Ex-post evaluation of development impacts from climate finance: much as a crop yield model was employed in the Bangladesh case study.
Example of use	"Simulating Dry Matter Yield of Two Cropping Systems with the Simulation Model HERMES to Evaluate Impact of Future Climate Change" (*European Journal of Agronomy*, 2015): This paper used HERMES to analyze the impact of double cropping systems on dry matter yield.
Output/Units	The primary output of the HERMES model is yield measured in t/ha. Depending on model specifications HERMES can produce additional outputs related to soil plant interactions such as soil moisture, measured by percent moisture volume.

Table A-3. Model Review for Category 3: Increased Energy-enabled Economic Output

Emissions Prediction and Policy Analysis (EPPA)	
Description	Developed by the MIT Joint Program on the Science and Policy of Global Change, EPPA is a CGE model used for economic projections and policy analysis. EPPA allows users to quantify the economic impact of emission mitigation policies (i.e., emissions limits, carbon taxes, energy taxes, tradeable permits, and technology regulation) and also model how different emission scenarios influence atmospheric chemistry and climate change. EPPA can be run as a standalone model or also in conjunction with MIT Earth System Model.
URL	https://globalchange.mit.edu/research/research-tools/human-system-model/download
Complexity	**Data requirements:** The global trade analysis project (GTAP) database is built into the EPPA model and provides necessary data on production, trade flows, economic data, and emissions. This information is aggregated in EPPA's model into 16 regions and 21 economic sectors.
In-house vs. outsourced use	Accessibility of the GTAP database within the EPPA model makes in-house use of EPPA seem feasible.
Cost of implementation and maintenance	EPPA is a publicly available model that can only be used for educational or research purposes (i.e., not commercial use). MIT does not provide any technical support or maintenance for EPPA, and users must also edit source code to reflect economic or technological changes. Thus, maintenance costs of the tool are unclear.
Use cases for CIF	(1) Investment plan and project design: can produce ex-ante project benefits and costs to evaluate project plans. (2) Exploration and collaboration with partners: macroeconomic results are understood widely so are effective at communication with local ministries of finance, development banks, or development partners. (3) Understanding tradeoffs between investment opportunities: By quantifying the economic costs associated with different emissions policies, EPPA can be used to better compare different investment strategies. (4) Ex-post evaluation of development impacts from climate finance: as CGEs were applied in the Indonesia case study.
Example of use	"Climate Change Policy in Brazil and Mexico: Results from the MIT EPPA Model" (*Energy Economics,* 2016): This paper uses the EPPA model to quantify the monetary costs associated with Brazil and Mexico meeting UN emissions commitments.
Output/Units	The model output of EPPA can vary by specifications. Under the economic specification, outputs include gross output by sector and output supplied to each final demand sector. These outputs can be considered in terms of energy (exajoules), emissions (tons), land use (hectares), population (billions of people), natural resource stocks (exajoules, hectares) and efficiencies (energy produced/energy used). More broadly, EPPA can also produce outputs related to water, land and atmospheric changes (i.e., sea level rise, GHG concentrations, soil and vegetative carbon, net primary productivity, and global mean temperature, among others).
Joint Impact Model (JIM)	
Description	JIM is an input-out model that quantifies the indirect impacts of investments on value added, employment, and GHG emissions (sum of CO_2 and non-CO_2 emissions). JIM can be used by countries seeking to meet standards under the Paris Agreement and to achieve the SDGs. As it relates to energy investments JIM uses data on revenue and power production associated with different investments to quantify macroeconomic and environmental impacts.
URL	https://www.jointimpactmodel.org/
Complexity	**Data requirements:** For corporate investments, the minimum data requirements include: fiscal year, country/region of operation, economic activity, sales, and direct employment. Additional data on procurement, wages, taxes, and net income can also be included for enhanced results.
In-house vs. Outsourced use	CIF already routinely uses JIM.
Cost of implementation and maintenance	JIM is publicly available, but users must request access through the JIM website and provide information on their organization and intended use.

Use cases for CIF	(1) Investment plan and project design: can produce ex-ante project benefits and costs to evaluate project plans. (2) Exploration and collaboration with partners: macroeconomic results are understood widely so are effective at communication with local ministries of finance, development banks, or development partners. (3) Understanding trade-offs between investment opportunities: JIM can compare the benefits of alternative ways of arriving at similar outcomes, e.g., hydropower versus solar development for achieving energy security. (4) Ex-post evaluation of development impacts from climate finance: JIM was also applied in the Indonesia case study.
Example of use	https://www.jointimpactmodel.org/publications
Output/Units	Model outputs quantify value added, greenhouse gas emissions, and employment. Value added considers the sum of wages, taxes, and savings and is expressed in a monetary value. Greenhouse gas impacts consider the sum of carbon dioxide and non-carbon dioxide emissions and is expressed in CO_2e. Employment impacts are expressed as the number of working age people. Employment impacts can also be reduced to consider female employment, formal employment, informal employment, and youth employment more specifically.
Global Trade Analysis Project (GTAP)	
Description	Developed by Purdue University, the GTAP model is a CGE model that enables users quantify costs associated with GHG abatement policies. (The model has other capabilities for uses beyond the energy and environment sector.)
URL	https://www.gtap.agecon.purdue.edu/models/current.asp
Complexity	**Data Requirements:** Data from the GTAP database can be incorporated into the model. This includes input-output data, macroeconomic data, data on bilateral trade flows, and energy data for reference years. **Other requirements:** A GEMPACK license (General Equilibrium Modeling Package) is needed to utilize the standard GTAP model.
In-house vs. outsourced use	The accessibility of the GTAP database within the model makes in-house use seem feasible.
Cost of implementation and maintenance	RunGTAP is a visual interface that allows users to run simulations in the GTAP model. RunGTAP can be downloaded for free. To use the GTAP databases a GEMPACK license is required. GTAP also has different licenses needed for users to access their GTAP databases (i.e., government/private sector licenses, academic licensees, consultant licenses, etc.). The costs associated with licenses are unclear.
Use cases for CIF	(1) Investment plan and project design: can produce ex-ante project benefits and costs to evaluate project plans. (2) Exploration and collaboration with partners: macroeconomic results are understood widely so are effective at communication with local ministries of finance, development banks, or development partners. (3) Understanding trade-offs between investment opportunities: GTAP can compare the benefits of alternative ways of arriving at similar outcomes, e.g., hydropower versus solar development for achieving energy security. (4) Ex-post evaluation of development impacts from climate finance: as CGEs were applied in the Indonesia case study.
Example of use	https://www.gtap.agecon.purdue.edu/models/Energy/default.asp
Output/Units	The primary outputs of GTAP are changes in GDP and macroeconomic consumption, both expressed in monetary terms. Abatement costs estimated by the model are expressed in monetary terms.
GCAM	
Description	Developed by the Joint Global Change Research Institute at the University of Maryland, GCAM is an integrated assessment model that considers interactions between energy, water, agricultural, land, economic, and climate systems to analyze (1) energy, water, and agricultural production and consumption (2) energy, food, and water prices, (3) trade flows, (4) land use, land cover, and carbon flows and (5) emissions and GHG concentrations. The model can be run for 14 geographic regions in the energy and economy module and for 151 regions in the agriculture and land module. Additionally, the model can be run to consider the period from 1990–2100, in 5-year increments.
URL	http://www.globalchange.umd.edu/gcam/

Complexity	**Data requirements:** To model energy demand and supply GCAM can use energy balances data from the International Energy Agency (IEA). However, these data are not provided in the GCAM model—users must purchase the data on their own. GCAM does provide R code to process IEA data for use in GCAM. To model land use changes, GCAM requires data on land use, land cover, harvested area, carbon characteristics, soil characteristics, and the value of unmanaged land. This information is stored in (.csv) files on GitHub and can be imported into GCAM. To model the economy, GCAM utilizes population and GDP data stored in (.csv) files on GitHub and can be imported into GCAM. This data comes from the UN, USDA, World BANK, IMF, and OECD, among other sources.
In-house vs. outsourced use	Compared with the EPPA model, in-house use of GCAM seems less likely due to the increased data collection and data transformation the user must perform.
Cost of implementation and maintenance	GCAM is an open-source tool whose source code can be downloaded from GitHub.
Use cases for CIF	(1) Investment plan and project design: By quantifying changes in production and consumption of different resources, GCAM can be used help promote targeted investment strategy in areas where resources are projected to become scarce. (3) Understanding tradeoffs between investment opportunities: By quantifying the economic costs associated with different policies and investments, GCAM can be used to better compare different investment strategies.
Example of use	"Projecting State-level Air Pollutant Emissions Using an Integrated Assessment Model: GCAM-USA" (*Applied Economics*, 2017): This paper utilized the GCAM model to project nitrogen oxides, sulfur dioxide, and $PM_{2.5}$ based on U.S. air pollution regulations.
Output/Units	Model outputs of this multi-sectoral model vary considerably. The agricultural module presents crop yields (kg/ha), the energy component in MWh, and water resources components in millions of cubic meters. The model can also quantify changes in emissions and atmospheric concentrations of greenhouse gases, carbonaceous aerosols, sulfur dioxide, and reactive gases.
ENVISAGE	
Description	Originally developed by the World Bank, ENVISAGE is a computable general equilibrium model that can be used to model how changes in GHG emissions impact dynamics between the economy and environment. Specifically, the ENVISAGE model can be used to analyze: (1) baseline GHG emissions; (2) Impacts to the economy from climate change; (3) adaptation to climate change; (4) policies targeting GHG emissions (i.e., carbon taxes, cap and trade programs); (5) the role of land use in climate change mitigation; and (6) the distribution of climate change impacts.
URL	https://mygeohub.org/groups/gtap/envisage-docs
Complexity	**Data requirements:** ENVISAGE is a GTAP-based model and therefore can be run to consider up to 140 regions and 57 sectors. It is unclear whether all data requirements for the model are stored within the GTAP database, or whether the user may be responsible or some data inputs.
In-house vs. outsourced use	The accessibility of the GTAP database within the model makes in-house use seem feasible.
Cost of implementation and maintenance	The implementation and maintenance costs associated with the ENVISAGE model are unclear.
Use cases for CIF	(1) Investment plan and project design: can produce ex-ante project benefits and costs to evaluate project plans. (2) Exploration and collaboration with partners: macroeconomic results are understood widely so are effective at communication with local ministries of finance, development banks, or development partners. (3) Understanding tradeoffs between investment opportunities: By quantifying the economic costs associated with different emissions policies, ENVISAGE can be used to better compare different investment strategies. (4) Ex-post evaluation of development impacts from climate finance: as CGEs were applied in the Indonesia case study.
Example of use	"Land-use Change Trajectories up to 2050: Insights from a Global Agro-Economic Model Comparison" (*Agricultural Economics*, 2013): This paper utilizes the ENVISAGE model to project future crop land use under different socio-economic and climate scenarios.
Output/Units	Model outputs quantify GHG emissions (tons) and economic impacts (GDP in monetary terms).