communications
earth & environment

ARTICLE

https://doi.org/10.1038/s43247-022-00468-9 OPEN

Integrating sustainability into climate finance by quantifying the co-benefits and market impact of carbon projects

Jiehong Lou[1]✉, Nathan Hultman[1], Anand Patwardhan[1] & Yueming Lucy Qiu[1]

High-quality development rooted in low-carbon growth, new jobs, energy security, and environmental quality will be a critical part of achieving multiple sustainable development goals (SDGs). Doing this will require the dramatic scaling up of new climate finance while maximizing co-benefits across multiple outcomes, including for local communities. We developed a comprehensive methodology to identify different levels of local co-benefits, followed by an econometric analysis to assess how the market values co-benefits through the clean development mechanism. We find that projects with a likelihood of delivering the highest co-benefits received a 30.4% higher price compared to projects with the lowest co-benefits. Project quality indicators such as the Gold Standard, in conveying higher likelihood of co-benefits, conferred a significant price premium between 6.6% and 29%. Our methodology of aligning co-benefits with SDGs and the results of co-benefits valued by the markets indicate approaches to bolstering social and political support for climate finance.

[1]School of Public Policy, University of Maryland, College Park, MD, USA. ✉email: jlou@umd.edu

We live in a world that is affected by climate change, that has finite resources, and that calls for global efforts to achieve a sustainable low-carbon future, where carbon benefits should be aligned with broader development goals[1]. Those diverse economic and development benefits created from climate actions, such as improving air quality, empowering women, improving farmers' livelihoods, or creating local jobs, often are termed "co-benefits." In many development contexts, and in many specific communities, these co-benefits are concrete and near-term, and are often seen as more directly valuable than carbon benefits. The co-benefits approach, therefore, could motivate action on climate change[2] and incentivize political support[3] by engaging a broader range of stakeholders[4]. In the context of sustainable development goals (SDGs), climate action is more than just one of the 17 SDGs, it has been shown to have strong synergies and trade-offs with other SDGs[4–11]. Clearly, a comprehensive understanding of the co-benefits aligned with SDGs presents potential to achieve climate change mitigation and non-climate objectives.

On the path to a low-carbon, sustainable growth transition, climate finance is a crucial aspect of achieving both climate and sustainable development goals—particularly through enabling large-scale investments in reducing greenhouse gas emissions and adapting to the adverse effects of climate change[12,13]. However, how the climate finance market values co-benefits remains poorly understood. This can bias policies[14,15] or otherwise limit the mobilization of climate finance, especially private finance[16], potentially reducing the real co-benefits delivered to local communities.

Current research on integrating sustainability criteria or co-benefits into sustainable investing has faced several challenges. First, while it is fairly simple to calculate the cost of projects, the co-benefits are much harder to measure or estimate because these benefits are often intangible or non-monetary (such as health co-benefits). Second, standards to measure these bottom-up or distributed co-benefits are undefined and inconsistent. Third, there is a lack of globally comprehensive reporting and assessments for the different co-benefits that map on to the different SDGs. Due to inadequate co-benefit data disclosure standards and performance metrics, these scattered and inconsistent approaches further prevent researchers from assessing the presence, extent, and determinants of co-benefits[17].

While the challenge of leveraging much larger amounts of climate finance is broadly recognized, only partial answers have been provided by previous research. Some qualitative research seeks to identify co-benefits of climate finance projects by a multiple-dimension–multiple-indicator methodology, ranging from simple project checklists[18,19], to a more complicated method of extracting co-benefit-related information and building up a profile of co-benefits for each project for comparison[20–25], to the most complicated method of multi-attributive assessment with a combination of indicators of qualitative, semi-quantitative, and quantitative natures[26–31]. These methodologies help elucidate the benefits but largely are blind to interactions between projects and market actors, particularly how much market actors value co-benefits. Another research strand evaluates co-benefits quantitatively but limits the scope to specific, easily measured and comparable categories, such as environmental indicators (e.g., CO_2, SO_2, etc.) or socioeconomic indicators (e.g., income, employment, etc.)[32–35].

While research has expanded quickly—particularly on developing co-benefit indicators and specific, measurable outcomes—there remains less understanding of the extent to which the presence of co-benefits, especially at the local level, is valued by investors. To address this gap, we first develop an analytical framework to categorize SDGs and local co-benefits (Fig. 1). We test this framework using econometric analysis of how co-benefits are valued by market actors in an application of climate finance: using historical experience with a similar, real-world experiment, the clean development mechanism (CDM). As the major international carbon offset mechanism under the Kyoto Protocol[36], the CDM was designed to lead to significant emission reductions that would both lower the cost of climate mitigation in developed countries and contribute to sustainable development in the host countries. It therefore provides a helpful historical experience that can illuminate connections between investor preferences and policy goals to support development outcomes and emissions reductions, with its nearly 8000 projects across 105 host countries, each of which generated tradable quantities of emissions reductions called certified emissions reductions (CERs). The link between the CDM and local co-benefits has been studied at some length via case studies and other qualitative approaches but assessments based on empirical data have been sparse[37]. To carry out this research, we also refine and improve data on the CDM from an existing database, by adding Emission Reduction Purchase Agreement (ERPA) dates and buyers' sectoral information and profit status for each project. Our dataset provides the most comprehensive listing of buyers and sellers in the CDM market.

By focusing on local co-benefits, this research highlights the importance of valuing co-benefits where projects are located, and how these projects deliver impacts on local communities. Accordingly, for this paper we ask two questions: (1) do potential co-benefits from CDM projects encourage buyers to pay more as reflected in the credit price? and (2) do CDM projects with external certification deliver a price premium based on their guaranteed co-benefits? To answer the question of whether co-benefits encourage a premium, we conduct an econometric analysis of CER prices for 2259 projects for the co-benefits based on a new SDG and co-benefits analytical framework. We find that a project with a likelihood of delivering the highest co-benefits received a 30.4% higher credit price compared to projects with the lowest co-benefits. To answer the second question of whether externally certified projects deliver a price premium, we add an investigation of the so-called the Gold Standard (GS) certification for CDM credits, which focuses on sustainable development benefits. We then perform another econometric analysis of a group of 2195 regular CDM projects and 64 "Gold Standard"-certified CDM projects through a combined technique of exact matching, propensity score matching, and regression adjustment. Our results show that project quality indicators such as the Gold Standard, by conveying higher likelihood of local co-benefits, conferred a significant price premium in the range of 6.6–29%. This paper adds to our understanding of the link between investors and co-benefits from climate or carbon benefits via the CDM, which is essential for unlocking potential climate finance from the private sector. The compelling evidence from our analysis illustrates the crucial importance of rooting co-benefits with the carbon benefits. It further adds to the discussion of the importance of co-benefits in mobilizing broader stakeholder engagement—two important components of which are the local communities and climate finance investors assessed in this paper.

Results

Assessing co-benefit valuation through an SDG co-benefit framework. The first approach we take is to assess market price premiums of co-benefits, as reflected in the CER prices for projects with different kinds of co-benefits. To do this, we develop a two-layer framework for categorizing the overall local co-benefits of carbon projects (Fig. 1 and Supplementary Fig. 1). The first layer captures the five categories of local co-benefits, while the second layer captures broader SDG dimensions. For this research,

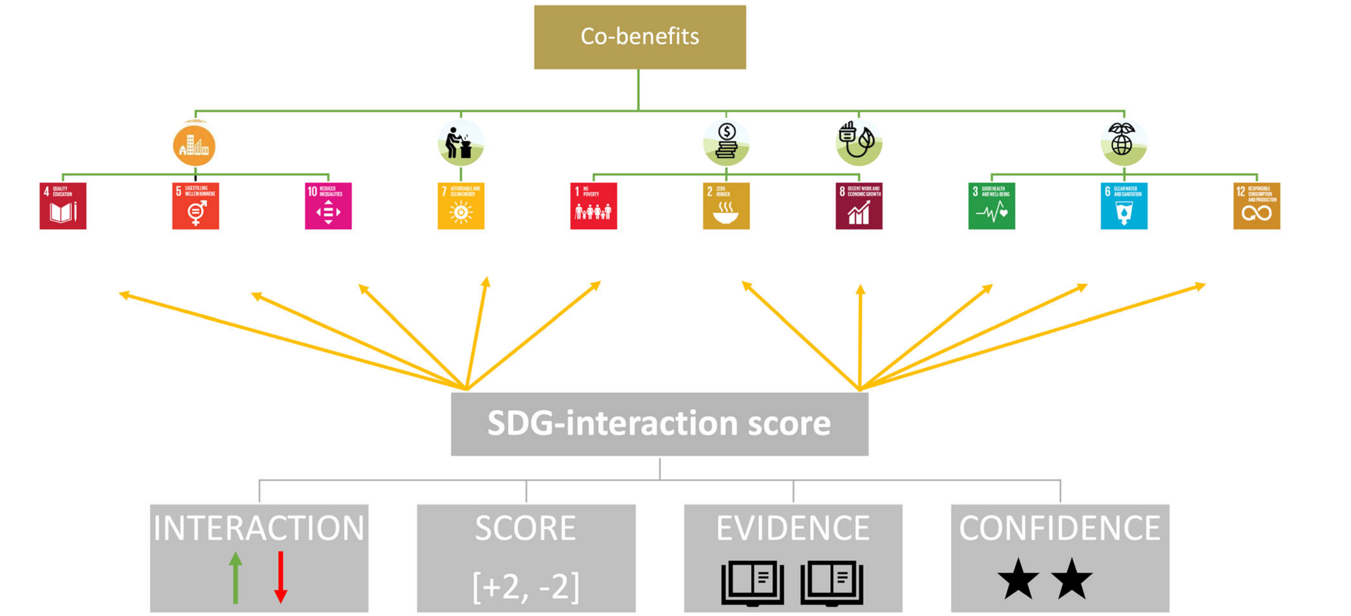

Fig. 1 SDG-interaction score system. We first establish five broad goals of co-benefits as indicated in the upper layer. Each of these five broad goals is associated with one or more SDG goals (second layer). We then produce an SDG-interaction score for each SDG, based on the specific project. Interaction components can be either positive and negative, which leads to aggregate positive and negative scores. We support the scores with evidence from the literature and confidence level assigned by the authors.Credit: Images from: UNFCCC COP23 and United Nations.

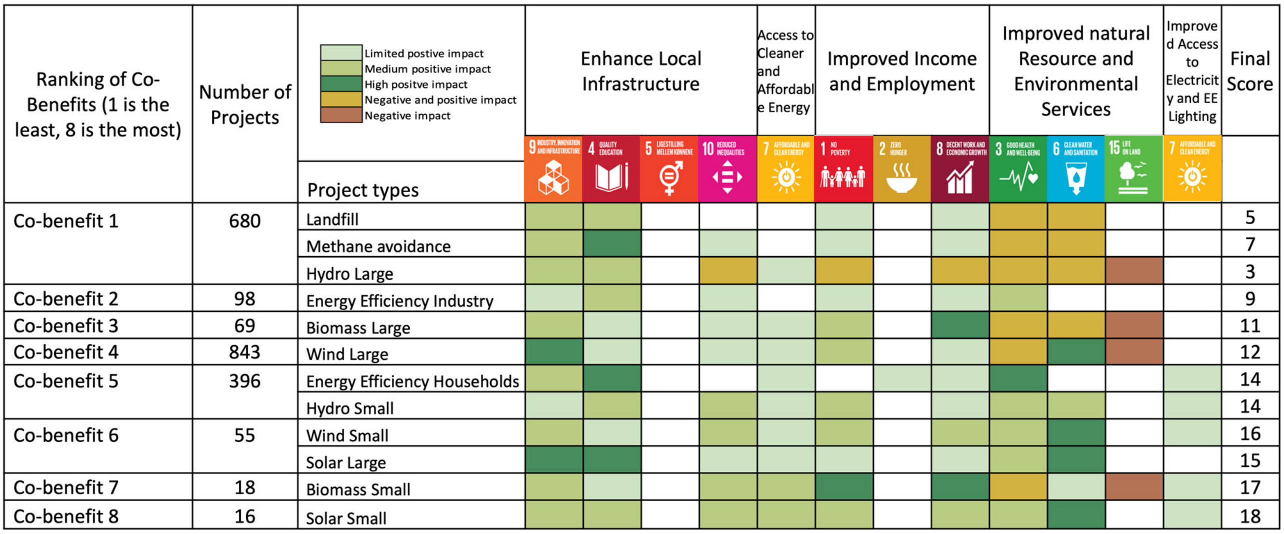

Fig. 2 Categorization of co-benefits of CDM projects based on simplified version of the SDG-interaction score platform. This figure illustrates different levels of potential local impacts from CDM projects as drawn from the literature. Green shaded colors indicate limited, medium, and high positive impacts. The yellow color points to the projects which might have both positive and negative impacts on the local communities. The red color indicates potential negative impacts. The higher score the co-benefit gets in the final score columns, the larger value of the co-benefit.Credit: Images from: United Nations.

we focus on project components that only have a local focus on local co-benefits. We adopted a methodology of analyzing SDG benefits from McCollum (2018)[38] and the IPCC special report on Global Warming of 1.5 °C[39]. We then assess the co-benefits of projects in a more quantified way. We used a systematic literature review to assess and score SDG targets and then linked those to the potential CDM co-benefits[37]. Detailed steps and methods of this framework are summarized in the "Methods" section and also the Supplementary Note 1.

Using this framework, we grouped 2195 projects into eight levels of co-benefits (Fig. 2) and sorted the level of co-benefits delivered into ranked categories. The framework was derived from an extensive structured literature review as described in Hultman, Lou, and Hutton (2020)[37]. A detailed table of this SDG framework with all the supporting literature can be found in Supplementary Table 1.

We then conducted the regression analysis by performing four specifications (Table 1). Across the four models, coefficients of co-benefits show an increasing trend. In both model 3 and model 4, the coefficients of co-benefits are all statistically significant at a 95% confidence level, except for the co-benefit 5 category, which includes energy efficiency (EE), households, and small hydro projects. There is a clear increasing pattern in all models except for co-benefit 6 in model 1 and co-benefit 7 in model 4. The overall trend is consistent across the four models. Our preferred model, model 3 indicates that after controlling for projects'

Table 1 Regression estimates of CER prices based on different co-benefits on CDM projects.

Models	Model 1 (Linear)	Model 2 (Linear)	Model 3 (Linear)	Model 4 (Log-linear)
Co-benefit 1 (The base case)	0	0	0	0
	(.)	(.)	(.)	(.)
Co-benefit 2	0.696**	1.816***	1.553***	0.111***
	(0.303)	(0.439)	(0.530)	(0.0393)
Co-benefit 3	0.829***	2.127***	1.803***	0.122***
	(0.301)	(0.472)	(0.598)	(0.0443)
Co-benefit 4	2.098***	3.348***	3.022***	0.222***
	(0.149)	(0.402)	(0.545)	(0.0404)
Co-benefit 5	0.139	0.0161	0.374	0.0346
	(0.163)	(0.168)	(0.437)	(0.0324)
Co-benefit 6	1.683***	4.138***	4.164***	0.315***
	(0.360)	(0.665)	(0.665)	(0.0493)
Co-benefit 7	3.440***	4.404***	4.417***	0.259***
	(0.688)	(0.740)	(0.740)	(0.0549)
Co-benefit 8	0.396***	3.493***	3.878***	0.304***
	(0.570)	(0.948)	(1.043)	(0.0773)
Year fixed effect (FE)	Yes	Yes	Yes	Yes
Project type FE	No	Yes	Yes	Yes
Project location FE	Yes	Yes	Yes	Yes
Credit buyer FE	Yes	Yes	Yes	Yes
Project size dummy	No	No	Yes	Yes
Gold Standard	1.906***	2.128***	2.127***	0.111***
	(0.406)	(0.408)	(0.408)	(0.0303)
No. of observation	2173	2173	2173	2173
Adjusted R^2	0.3073	0.3139	0.3138	0.328

The dependent variable in all the first three models is CER prices and is natural log of CER prices in Model 4. Coefficient estimates are reported in this table. Standard errors are in parentheses. Co-benefit 1 is the base case. We control for project location fixed effects, credit buyer fixed effects, project type fixed effects, and year fixed effects in the models. Model 1 conducts OLS regression without controlling for the project type and project size fixed effect. Model 2 controls for project type, and model 3 controls for both project type and project size. Model 4 uses log-linear specification by taking the natural logarithm of the CER prices. We estimate the four multiple specifications to ensure robust results.
*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

features and sellers' background, projects with a likelihood of delivering more co-benefits receive higher CER prices. For example, projects in co-benefits level 2 are likely to have an average \$1.53/tCO_2e (11%) price premium compared to projects in co-benefits level 1. Additionally, we plot the point estimates and 95th percentile confidence intervals of co-benefits of model 3 and model 4 to show the trends visually in Fig. 3. The overall results support our initial hypothesis that customers value climate finance projects with high co-benefits more and this is reflected in the market price.

Impact of certified premium CDM projects on perception of co-benefits and price. In addition to allowing an evaluation of standard CERs, the historical experience of the CDM provides another approach to evaluate the link between anticipated benefits of projects and the overall market price. This approach is based on the presence of a small subset of CDM projects that sought and acquired a third-party quality label called the "Gold Standard". Unlike the regular CDM, which makes no claim to the specific projects or co-benefits that the CDM generates, these independent labels or other indicators can potentially send a signal to CER purchasers that a labeled project has higher co-benefits, and this might then stimulate higher market prices for the CER prices[26]. This certification standard provides an add-on methodology to evaluate the quality of the project across several dimensions, including specific safeguards and requirements for project type. The standard establishes a methodology that certifies projects that not only achieve the goal of emission reductions but also can deliver on at least two SDGs that are important to ensuring that the benefits are delivered to local communities[40,41].

We can thus compare GS projects to regular CDM projects to estimate the actual price premium a buyer is willing to pay for a Gold-Standard-labeled CDM project. To do this, we conducted a propensity matching and exact matching analysis with five alternate models (Table 2). These five models represent different matching techniques, which are explained in detail in the "Methods" section. Across the five models, coefficients of the treatment effect are all statistically significant at a 90% confidence level. The difference between the CER prices of Gold Standard and regular CDM shows consistent trends in all the five models. Model 1 indicates that statistically controlling for differences in projects' features and sellers' background, Gold Standard projects received a price premium of \$1.90/tCO_2e (10.3% of CER price increase due to the Gold Standard Certification in Supplementary Table 2). Results of models 2 and 3 indicate that when matched on their propensity to receive Gold Standard, projects with Gold Standard displayed a higher price premium. Compared to matched projects without certification, the price premium is from \$4.21/tCO_2e (29%) to \$2.58/tCO_2e (14%). However, due to the poorly matched results from model 2, estimates from model 2 might overestimate the impact of Gold Standard. Model 4 displays an estimate of the effect of Gold Standard for CDM projects that, within each credit buyer's country, were predicted to have statistically similar propensities of obtaining Gold Standard certification. The price premium from model 4 is \$2.33/tCO_2e (11.2% of CER price), close to the results from model 3. Model 5 presents an estimate of the price premium where each credit buyer's country and project location (country level) should be exactly matched, were predicted to have statistically similar propensities of obtaining certification. The price premium from model 5 is \$1.13/tCO_2e (6.6%), which is also expected. In model 5, due to our limited number of projects in the treatment group, eventually, we only have two locations of projects left in the model: China and Vietnam.

Heterogenous effects analysis. One potentially influential factor in co-benefit valuation is whether the company or the geographical location of buyers matters to their relative priority for the quality of sustainable development versus simply low-cost credits[42]. We used information on 218 companies across 21 countries to study the credit buyers' behavior by country and company. Supplementary Fig. 8 presents the scale of purchasing CDM projects and the average CER prices aggregated by country, showing country-level variation from the average global carbon price.

Table 3 shows the results of all company-level regression models. One set of results with statistical significance relates to the location of the projects. For example, credit buyers paid higher prices for CERs generated in Africa compared to those based in the other regions. Results indicate that a 10% increase in the proportion of projects that are located in Asia is associated with a \$0.42/tCO_2e (a 1.9%) decrease in the CER prices compared if the projects are located in Africa. In terms of credit buyers' industry or for-profit and not-for-profit status, we do not find a price difference among them. This indicates that in the compliance carbon markets, prices of CERs do not differ based on buyers' profit status or sectors.

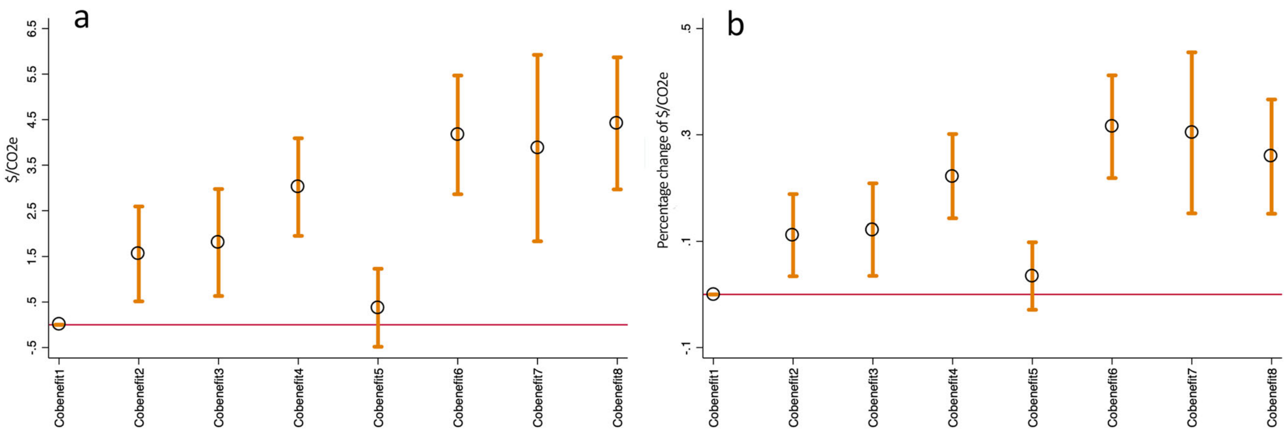

Fig. 3 Point estimates of CER prices based on different co-benefits. a Point estimates from linear model. **b** Point estimates from log-linear model. Base case in both models is co-benefit 1. The black circles represent the point estimates of each co-benefit compared to base case, which are obtained from running the regression. The orange vertical bars represent the 95% confidence intervals of the estimations.

Table 2 Treatment effect of Gold Standard on CDM projects.

Models	**Model 1** Full regression	**Model 2** Propensity score matching with all 9 covariates	**Model 3** Propensity score matching at 5 continuous covariates	**Model 4** Exact matching on the credit buyers	**Model 5** Exact matching on the credit buyers and project location
TREAT (Gold Standard)	1.909**	4.210***	2.581***	2.338*	1.130*
	(0.858)	(1.124)	(0.939)	(1.180)	(0.616)
Year fixed effects (FE)	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes
Credit buyer FE	Yes	Yes	Yes	Yes	Yes
Project location FE	Yes	No	No	No	Yyes
Special cases					
Wind	1.130*** (0.425)	3.426 (2.135)	0.893 (1.069)	2.136**−0.833	2.514** (1.148)
Methane avoidance	−2.715*** (0.900)	−4.546 (6.943)	−1.839* (1.012)	0.915−1.464	0.119 (1.678)
Vietnam	4.417* (2.360)				13.11*** (2.436)
F Joint test	6.0***	15.1***	2.9**	5.09***	2.05*
No. of observation	2251	378	378	294	126
TREAT	64	63	63	49	21
UNTREAT	2187	315	315	245	105
R^2	0.3406	0.9521	0.3404	0.2062	0.8327

The dependent variable in all five models is CER price. Coefficient estimates are reported in this table, with standard errors in parentheses. Standard errors are clustered at credit buyers' company level. We control for project location fixed effects, credit buyer fixed effects, project type fixed effects, and year fixed effects in the model. Due to the variation of project location and variation of treatment is highly collinear, we do not include project location fixed effects in models 2–4. Standard error at the company level.
*$p<0.10$; **$p<0.05$; ***$p<0.01$.

We further evaluate the buyers' preference for the Gold Standard certification in the compliance carbon markets through the hedonic price method. We classify the credit buyers either through their types of sector (Fig. 4a), or their types of profit status (Fig. 4b), and show the resulting point estimates, with more detailed results presented in Supplementary Tables 3 and 4. Figure 4a shows that the results of the analysis comparing the Gold Standard CDM projects and regular CDM projects are statistically significant in the following industries: industrial and material, carbon-related (including carbon assets management, carbon consulting management, etc.), and government and foundation. If these buyers operate in the industrial and material sector, the results indicate that the price premium of Gold Standard CDM projects paid by credit buyers is \$6.50/tCO_2e or 32% more, compared to those regular CDM projects. For credit buyers focused on carbon-related asset management, the price premium was \$2.90/tCO_2e or 14% more if the projects obtained Gold Standard certification. Buyers from government entities and foundations are willing to pay \$1.60/tCO_2e or 15% more if the projects are certified by the Gold Standard. The rest of the coefficient estimates of interest are not statistically significant. We find no price difference between Gold Standard certified projects and regular CDM projects in other industries.

Figure 4b presents the results of analyzing the different preferences over Gold Standard-certified CDM projects and regular CDM projects based on broader buyers' status as for-profit and not-for-profit. The results from the for-profit entities have no statistical significance, while the results from not-for-profit (government and multilateral development banks (MDBs)) entities continue to have statistical significance. The price premium for Gold Standard CDM projects is \$2.30/tCO_2e or 19% more from government entities and is \$0.60/tCO_2e or 7%

Table 3 Buyer company-level regression results.

Models	Model 1 (Linear)	Model 2 (Log-linear)	Model 3 (Linear)	Model 4 (Log-linear)
Number of projects purchase	−0.003 (0.010)	−0.0003 (0.0007)	−0.003 (0.010)	−0.00003 (0.0007)
Buyer's profit status				
Foundation	0 (.)	0 (.)		
Government	−0.288 (1.907)	−0.079 (0.180)		
MDB	1.247 (2.136)	−0.075 (0.155)		
Private global	1.614 (1.687)	0.055 (0.122)		
Private local	1.502 (1.687)	0.047 (0.122)		
Buyer's sector				
Business consulting and others			1.729 (1.730)	0.720 (0.124)
Consumer discretionary			0.844 (1.931)	0.006 (0.139)
Consumer staples			0.248 (2.350)	−0.048 (0.169)
Energy			1.547 (1.834)	0.078 (0.132)
Financials			1.401 (1.728)	0.040 (0.124)
Financials (special)			1.042 (1.742)	0.006 (0.125)
Foundation			0 (.)	0 (.)
Government			0.0887** (1.870)	−0.084 (0.134)
Industrials			2.077 (1.864)	0.099 (0.134)
Materials			2.326 (1.985)	0.871 (0.143)
Utilities			1.783 (1.783)	0.070 (0.128)
Buyer's purchased project size (%)	−0.346 (0.527)	−0.038 (0.038)	−0.473 (0.538)	−0.048 (0.039)
Buyer's purchased Gold Standard (%)	4.173*** (0.923)	0.262*** (0.067)	4.107*** (0.944)	0.267*** (0.068)
Buyer's project portfolio				
Asia & Pacific (%)	−3.988** (1.868)	−0.311** (0.135)	−0.350** (1.881)	−0.333** (0.135)
Latin America (%)	−4.825** (2.199)	−0.438*** (0.159)	−5.135** (2.215)	−0.482*** (0.160)
Middle- East (%)	−6.081 (3.741)	−0.486** (0.271)	−7.568* (3.867)	−0.620** (0.278)
Europe & Central Asia (%)	−2.369 (4.737)	−0.206 (0.343)	−2.791 (4.815)	−0.232 (0.346)
Africa (%)	0 (.)	0 (.)	0 (.)	0 (.)
Buyer's location fixed effect[a]	Yes	Yes	Yes	Yes
Observations	218	218	218	218
Adjusted R^2	0.207	0.204	0.195	0.203

The dependent variable is CER price in models 1 and 3 and natural log of CER price in model 2 and 4. Coefficient estimates are reported in this table. Standard errors are in parentheses.
*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.
[a]We found that a credit buyer's location affects the CER prices. CER buyers based in Oceania, specifically, purchasers located in Australia or New Zealand procured at higher CER prices than those based in Europe and Asia. With Australia as the base case, 14 out of 20 coefficient estimates are negative and statistically significant. This could be because of Australia's early movement towards a cap-and-trade program with a high fixed domestic price of carbon credits. Credit buyers located in the UK purchased CERs at a price discount of $8.90 on average (55%). There is no statistically significant difference between prices from buyers located in North America, Australia, or Europe.

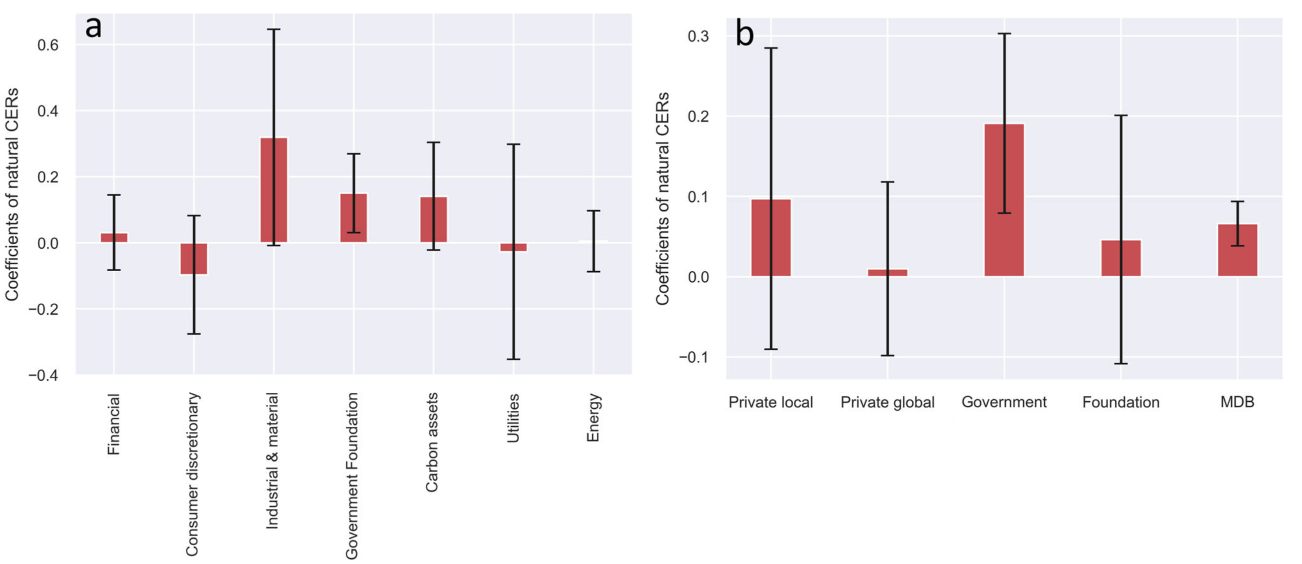

Fig. 4 Point estimates of interaction between treatment (Gold Standard) and different types of buyers. a Coefficients of interaction between buyer's sector and treatment. **b** Coefficients of interaction between buyer's profit status and treatment. It shows that the treatment effects differ across buyer's sectors. The red bars represent the point estimates of each interaction, which are obtained from running hedonic models. The black vertical bars represent the 95% confidence intervals of the estimations.

more from MDB, respectively. The rest of the coefficient estimates of interest are not statistically significant. The results deliver an important message that non-for-profit organizations value co-benefits more, and they are pushing the assessment of the co-benefits in the local communities by purchasing the Gold Standard-certified CERs with a price premium.

Discussion

Overall, our results demonstrate that a project with a likelihood of delivering the highest co-benefits received a 30.4% higher credit price compared to projects with the lowest co-benefits. We also find that project quality indicators such as the Gold Standard, in conveying higher likelihood of local co-benefits, conferred a significant price premium in the range of 6.6–29%. Our results show that organizations supported by the public funding are willing to pay more for projects with higher co-benefits for the CERs with a Gold Standard certification in the compliance carbon markets. However, we do not see that the private sector is willing to pay more in general. When we break the entire private sector down further in detail, we observe certain sectors, such as industrial and material, and carbon-related services (including carbon assets management, carbon consulting management) are willing to pay more for projects with higher co-benefits for the CERs with a Gold Standard certification. Their willingness to pay is even higher than for public entities. One possible explanation of carbon-related asset management paying more for Gold Standard projects is that they are the experts in the carbon market and have deeper awareness of the add-on value that the Gold Standard provides to the projects. We highlight the potential implications of communicating the value of co-benefits to a broader set of stakeholders, including investors, local communities, project developers, and policymakers, to fully capitalize on potentially positive impacts. Additionally, our results show that investors are willing to pay more for projects in certain locations (e.g., African countries) or that have certain project-related attributes (e.g., small wind, small solar, and small biomass projects).

As countries scale up climate finance, it is clear from the historical experience with CDM that an expanded global financial flow to support projects that reduce greenhouse gas emissions can create tension in providing financial return while still delivering co-benefits and carbon benefits. And while co-benefits are difficult to monetize, they represent the real impact on local communities and are a critical component of broader national development strategies. From a policy perspective, it is also essential to set a framework that can place a high strategic value on delivering local co-benefits to receiving communities through climate investment. In this framework, public funding can play an enabling role at the early stage, mobilize for-profit entities to engage in climate finance, optimize the value of climate investment, and support delivery of real and lasting sustainability. Our results highlight the importance of effective communication of co-benefits, aligning with SDGs, among the entire society.

While CDM experience was heterogeneous in its ability to deliver community co-benefits, those benefits were more likely to manifest in projects following general best practices for finance, including significant community consultation and engagement in the planning and implementation process. Discussions on any new system focused on sustainable development or climate finance goals should include mechanisms that support local co-benefits. Additionally, the new system should provide safeguards of preventing undesired effects derived from climate actions. To do this, the international climate community can establish safeguards in three channels. First, learn lessons from extensive experience in the Reducing Emissions from Deforestation and forest Degradation (REDD+), which provides an improved understanding of safeguards associated with its implementation[43]. Policy should seek to promote safeguards, such as effective participation of local communities[44]; add-on incentive mechanisms[45]; the necessary level of social and political support by linking the co-benefits further to SDGs[3], to avoid negative impacts from climate action. Second, given that socio-economic conditions are recognized to co-improve SDG indicators with climate policies[9], policymakers should make a joint effort to implement both and in doing so, should focus their implementing policies centrally on the reporting and transparency needed to evaluate progress on this goal. Finally, national or subnational prioritization for projects should generate co-benefits that are closely related to households, that have a direct positive impact on them, and that enables wider societal and systems transformation.

Our research utilized variations in the co-benefit valuation through the SDG co-benefit framework to establish a correlation between co-benefit valuation and carbon prices for the regular CDM projects, and a causal connection between project quality indicators, which guaranteed higher co-benefits delivered, and carbon prices for the CDM Gold Standard projects. This approach fills the sparse comprehensive quantitative analysis gap based on empirical data in the co-benefit literature[38]. More importantly, our model provides a way to better link co-benefits and local communities robustly and in a way that is suitable for understanding policy priorities in a broader setting. Second, our results could be further elucidated and complemented by qualitative analyses that focus on local knowledge and communication in places where projects are located. One of our findings is that certain regions gain more attention from investors due to co-benefits. Therefore, a future qualitative analysis would add depth and further context to how this attention is experienced and what could be gained by adjusting or enhancing this aspect. Finally, it contributes to the research on preventing undesired effects derived from climate action. The SDG co-benefit framework developed here can relatively easily be applied in other contexts of sustainable infrastructure investment. It allows for evaluating co-benefits either at the project level or aggregated levels such as region or country. The framework could be enhanced in other ways through project evaluation reports or interviews. This and similar assessment frameworks can assist the sustainable finance area by providing some guidelines for including these considerations in the new sustainable development era.

Our paper provides strong evidence that the carbon market values co-benefits through investors' willingness to pay more for projects with higher co-benefits. Nevertheless, several limitations are worth noting. First, the SDG interaction scores are based on the authors' judgment supported by a large literature review. While we have sought to include transparency on these elements (for example, through the confidence scores), this could be approached differently with a structured expert elicitation or other techniques. Second, our assessment of co-benefit valuation through the SDG co-benefit framework is based on the project technology types. Further extension of this current study on assessing the link between co-benefits and financing can be developing more fine-grained resolution based on individual project level to capture the variations of co-benefits of each project. Third, our sample focused on a specific mechanism, CDM, a compliance carbon market, and there is a need to test this approach across other mechanisms and settings (e.g., the voluntary carbon market, sustainable development mechanism). Finally, we did not assess CDM afforestation/reforestation (CDM-AR) projects due to their significantly different characteristics. However, we believe the results from this study might provide some perspective on enhancing the social and financial viability of CDM-AR-type projects, including implementation of

Article 6 of the Paris Agreement. The evidence of investors' willingness to pay more for projects with higher co-benefits could also support appropriate AR projects given that such projects can potentially offer multiple economic, social, and environmental benefits. A sectoral approach, such as through a new sustainable development mechanism, would potentially enable the host countries to scale up AR projects to achieve both emission reductions and sustainable development benefits.

Methods

Build up interactive SDG co-benefit framework. From our previous systematic literature review[37], we find that a great deal of variation in co-benefits existed not only among project types but also within project type. In this section, we take one step further to assess the co-benefits of these projects in a more quantified way by drawing up studies of scoring exercise at the level of the SDG targets to better understanding the interaction between the CDM project technologies and the SDG dimensions. The two primary studies on this topic are[38] and the Intergovernmental Panel on Climate Change (IPCC) special report Global Warming of 1.5 °C[39]. Both studies have conducted thorough research on the potential SDG targets from the deployment of mitigation options. Our paper adopts the structure of integrating the SDG targets into the mitigation options from both studies, while adding another layer of five co-benefit criteria on top of this structure. Thus, the final structure of the assessment is presented in Supplementary Fig. 1.

Under each SDG target, we assign an SDG-interaction score from this specific SDG target and the project. The SDG-interaction score is a seven-point scale score. Interaction between outcomes of the CDM projects and the SDG targets can be positive and/or negative. For the positive interaction, we have "high impact", "medium impact", and "limited impact" scales, and for negative interaction, we have "minor damage", "medium damage" and "massive damage". Additionally, we present the validity of the results in the literature by examining the quantity, quality, and consistency of the literature into four scales, limited, medium, robust, and extensive. Eventually, we assign the current level of confidence ("low", "medium", "high") to each SDG interaction based on the previous two aspects. This bottom-up direction of assessing the SDG interaction scores eventually can be aggregated at the level of co-benefit criteria. Our implication assumption is that the SDG goals are weighted equally, despite those countries may have different focus areas on sustainable development based on their national development priorities.

Data. Our data of the interactive SDG co-benefit framework is based on 84 academic peer-reviewed and grey studies conducted on the topic of carbon finance and community co-benefits from a systematic literature review search. The primary data source for economic models is the UNEP DTU CDM/JI Pipeline Analysis and Database (CDM/JI Pipeline). Additional information, such as ERPA dates, is extracted by Python from CDM documents in PDF format on the UNFCCC CDM projects site. To check the accuracy of the ERPA dates extracted by the computer, we adopted two methods to validate the data (see Supplementary Note 2: Accuracy of the ERPA Dates). We include 2259 CDM projects in our paper. The dataset covers 20 project types and two project sizes[46]. We present the statistical summaries of the data in Supplementary Table 5. We also plot the distribution of CER prices in Supplementary Fig. 9. Within these 2259 CDM projects, 1655 are regular CDM projects, and 64 are Gold Standard CDM projects. Detailed results segregated by project types and sizes are listed in Supplementary Table 6.

The underlying assumption of our analysis is that carbon prices (including any additional premiums from non-carbon sustainable development benefits) will compensate for the opportunity costs in the project, including transaction and implementation costs. For most of the CDM projects, additional revenue from carbon prices will help the CDM projects pass the additionality requirement. Because CDM projects need to demonstrate that projects are not viable unless carbon benefits are considered (i.e. with a non-zero carbon price). This assumption is valid for most CDM projects due to the additionality requirement they must pass, particularly when using financial additionality to meet the additionality requirement. During this additionality requirement, it is not supposed to include monetized co-benefits, which is precisely why projects with co-benefits are valued more highly by investors. However, CDM-AR projects suffer from particularly high opportunity costs, transaction costs, and implementation costs[3,47–50]. For example, the World Bank BioCarbon Fund, the major credit buyer holding17 out of the 66 CDM-AR projects[51], reported that the transaction costs of CDM-AR projects exceeded \$1 per tCO_2e, higher than any other CDM project type[52]. As a result, the World Bank adopted a default price in financial analysis of CDM-AR projects[51]. Also, in the case of CDM-AR projects these costs are likely to be higher since they involve land and property rights and more complex implementation arrangements[53]. In addition, the high opportunity costs of land and labor are well discussed in the CDM-AR literature[54–57]. These challenges can complicate evaluation of the co-benefits of the CDM-AR projects and lead to the failure of these projects[3,54]. Therefore, in our analysis, we did not include CDM-AR projects due to these characteristics as well as the small number of registered projects (a total of 66 registered projects). As a result, we believe that the assumption of our analysis is reasonable.

Credit buyers. The CDM mechanism creates CERs as an important share of the global carbon markets. Like the regular markets, the demand side of the CERs is from carbon credit buyers. CDM credit buyers can be categorized into three groups, the first group called compliance buyers who are seeking to buy offsets for compliance in the EU ETS and other regional schemes; the second group called sovereign buyers, mainly Annex I parties, who are obtaining CERs directly to meet their quantified emission limitation and reductions obligations (QELRO) commitments under the Kyoto Protocol; the last group contains MDBs and carbon funds[58]. We further divide credit buyers into different categories by using two classification systems. First, credit buyers (company level) are classified into 14 industries by their primary business activities using the Bloomberg Industry Classification Systems (BICS). Second, credit buyers are also categorized into five statuses based on their profit status, e.g., local private companies, global private companies, government entities, MDBs, and foundations.

Definition of co-benefits (non-carbon benefits). Although the idea of co-benefits has attracted increasing attention from governments, NGOs, financial institutions, and academic research in recent years, there is no consensus on a concrete definition or agreed list of what counts as a co-benefit[59]. The IPCC considers co-benefits as "the positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare"[60]. In this paper, we focus on a smaller subset of co-benefits, particularly on co-benefits to local communities as a result of CDM mitigation actions (carbon projects) that are targeted at addressing global climate change. Thus, we adopted and adjusted the co-benefits description from the World Bank the Community Development Carbon Fund (CDCF) 2013 report on key community outcomes, where five broad areas are listed. These five areas capture the complex dimensions of co-benefits. The co-benefits of this paper cover the following five areas: Enhanced local infrastructure (e.g., roads, health clinics, schools, water, parks, community centers, etc.); access to cleaner and affordable energy for heating and/or cooking; improved income and employment; improved access to electricity and/or energy efficient lighting; and improved natural resource and environmental services (e.g., reduced pollution, natural resource conservation, forest protection, biodiversity).

Definitions of other terms. *Climate finance* is defined as the public and private financial flows used to support mitigation and adaptation action to address climate change[61,62] There are currently two types of *carbon markets* for carbon offsets: compliance and voluntary markets. The market settings are different for the two markets. In the compliance (mandatory) market, buyers are primarily motivated to purchase offsets that can provide a more economic sense to reduce emissions to fulfill their lawful requirements, such as in a cap-and-trade regime[63]. The voluntary carbon market grew later compared to the compliance carbon market. It picked up in the late 2000s and kept a relatively stable trend until 2017. While in the voluntary markets, buyers (for example, companies) are primarily motivated by their social responsibility and concerns about climate change to reduce their emissions[64,65]. Multi-national, private, for-profit companies make the bulk of voluntary offset purchases by volume. *Official Development Assistance (ODA)* is defined as the aid from government entities to developing countries with a target to promote economic development and welfare[66]. *Carbon benefits* of CDM projects are defined as the anthropogenic emissions of greenhouse gases by sources being reduced below those that would have occurred in the absence of the registered CDM project activity[46].

Empirical strategies

Main model. Our main model is expressed in the following regression equation:

$$Y_{it} = \beta_0 + \beta_{1-8}(\text{Co}-\text{benefit}_{1-8}) + \beta_9 X_{it} + \gamma_i + \delta_i + \varphi_i + \omega_t + \theta_i + \varepsilon_{it} \quad (1)$$

where i indicates projects, and t indicates years when the credit purchase agreement was signed. In all models, the dependent variable Y_{it} is the CER price for each project. The variables of interest are Co-benefit$_{1-8}$, with their coefficients β_{1-8} indicate the effect of different levels of co-benefits on the CDM projects. We also control for a group of other variables listed in Supplementary Table 7, e.g., project location fixed effects (γ_i), credit buyer fixed effects (δ_i), project type fixed effects (φ_i), year fixed effects (ω_t), and project size dummy (θ_i). Finally, the error term captures unobserved factors affecting our dependent variable that changes over the year.

Hedonic model. The hedonic model is expressed in the following regression equation at credit buyers' company level, where CER prices can be explained as a function of credit buyers and project characteristics[67,68].

$$\begin{aligned} P_{\text{CERi}} = f(&\text{numprojects}_i, \text{location}_i, \text{industry}_i, \text{status}_i, \text{GS}_i + \text{projectsize}_i \\ &+ \text{portfolio}(\text{asicapacific}, \text{latinamerican}, \text{middleeast}, \text{africa}, \text{centraluropean})_i) + \varepsilon_i \end{aligned} \quad (2)$$

where i indicates companies. In all models, the dependent variable $P_{\text{CER}i}$ is the average CER price paid by company i. We also control for a group of variables such as, numprojects$_i$ is the number of offset projects under management; location$_i$ is a categorical variable indicating the country where the credit buyer i is located, GS$_i$ is the proportion of projects that have Gold Standard certification. We also control for investment portfolio in terms of project regions. Thus, asicapacific$_i$ is the proportion of projects that company i invests in Asia and Pacific region, africa$_i$ is the proportion of projects that company i invests in Africa, the same to the latinamerica$_i$, centraleuropean$_i$, middleeast$_i$. Finally, ε_i is an error term assumed to be normally distributed.

Matching. In our study, treatment is if a project receives a Gold Standard certification. The control group includes all the regular CDM projects. The rationale behind matching is to identify (based on the available covariates) a control group of projects with similar characteristics to a treated group of projects for comparison. Thus, the selection of covariates should be those variables that are thought to be related to the outcome (CER prices), but not the treatment[69]. Our strategy is to perform a propensity score matching at the level of five continuous variables. Beyond that, we also conduct the exact matching using two scenarios. Scenario 1 performs exact matching at the buyers' country level, and Scenario 2 conducts exact matching at both buyers' country and project location level. After finding good matches for the treatment group, the model will be adjusted by running a regression to control for the fixed effect from contract year, project type, project location, and buyers' location.

Python and Stata are used jointly for data analysis. Supplementary Fig. 10 shows that there is overlap in the range of propensity scores across the treatment and comparison group, which we called the "common support"[69,70]. Assessing the common support condition ensures that any combination of characteristics observed in the treatment group can also be observed among the control group. Additionally, diagnostic tests for balancing of covariates are shown in Supplementary Fig. 11. We can see that matching did a quite good job at balancing the covariates across the treatment and control group, with all (except one) p-values from both the KS-test and the grouped permutation of the Chi-Square distance after matching to be >0.05.

Our model is expressed in the following regression equation:

$$Y_{it} = \beta_0 + \beta_1(\text{Treat}_{it}) + \beta_2 X_{it} + \gamma_i + \delta_i + \varphi_i + \omega_t + \varepsilon_{it} \quad (3)$$

where i indicates projects, and t indicates years. In all models, the dependent variable Y_{it} is the CER price for each project. The variable of interest is Treat$_{it}$, with its coefficient β_1 indicates the effect of Gold Standard on CDM projects. We also control for a group of continuous covariates listed in Supplementary Table 7, project location fixed effects (γ_i), credit buyer fixed effects (δ_i), project type fixed effects (φ_i), and year fixed effects (ω_t). Finally, the error term captures unobserved factors affecting our dependent variable that changes over the year.

Matching techniques. Model 1 in Table 2 conducted OLS regression using the nine covariates that used to estimate the propensity to receive the treatment. That is, model 1 displays the difference in being Gold Standard CDM projects and regular CDM projects by controlling for the nine covariates. Model 2 through model 5 show results of estimates by using different matching techniques. Models 2 and 3 only used propensity score matching, while models 4 and 5 used the combined exact matching and propensity score matching technique. The difference between models 2 and 3 is the number of covariates used to obtain the results. In model 2, we perform the propensity score technique for all nine covariates, including both continuous and categorical covariates. In model 3, we only conduct the propensity score with the five continuous covariates. The models of interest are models 4 and model 5. In model 4, we perform the exact matching at the credit buyers' country level, in order to obtain the impact of Gold Standard on projects within the same country of buyers. In model 5, we restricted our model further to conduct exact matching on both credit buyers' country level and also the projects' location level. Model 5 is the most restricted model among these five models. We lost some observations due to model restriction in model 5, and we only obtained 21 projects in the treatment group.

Balancing test. We adopted the standardized differences (SD) technique, which is the standardized difference of means, to assess the differences between multiple variables of the treatment and control groups[71] in Supplementary Table 8. If there is no big difference between these two groups, we can conclude that there is adequate balance between these two groups of observations. Before matching Supplementary Table 8(a), the treated and untreated groups are unbalanced. When we do propensity score matching at both categorical and continuous covariates level Supplementary Table 8(b), we still did not get balanced groups. However, in the last test Supplementary Table 8(c), when we only conduct propensity score matching at the continuous covariates level, we get balanced groups.

Robustness checks for regular CDM projects. Many factors can influence the CER prices as indicated in Supplementary Table 7. One of the many factors is the 2008 financial crisis, which is the main cause of the price drop of CERs in that year. The price decreased by about 50%[72]. Thus, we dropped the 461 projects with a signed ERPA date of 2008, because we think that the year 2008 would have an impact on the CER prices. We re-ran the analysis with the remaining 1744 projects. We get very similar results (results are presented in Supplementary Table 9) across all four models compared to the results in Fig. 3 and all coefficient estimates of variables of interest deliver a similar increasing trend.

Robustness checks for regular Gold-Standard CDM projects. We conducted two robustness checks for our matching analysis. First, we replaced the credit buyer's country information with the indicators representing the health of a country's economy, such as GDP per capita, employment rate, government expenditure, and inflation rate. We get very similar results (results are presented in Supplementary Table 10) across all five models compared to the results in Table 1. All coefficient estimates of Gold Standard treatment are statistically significant. This indicates that our models are quite robust. Second, we conducted a "placebo" test by randomly selecting 50% of the data from our control group and artificially assigning them into the treatment group. By doing that, we created a "fake" treatment group, that is, a group that we know was not affected by the Gold Standard. we estimated the models by using the "fake" treatment, and the results are presented in Supplementary Table 11. All the coefficients of treatment effect are not statistically significant. Since we do not find that there is a difference in the absence of the real treatment, Gold Standard certificates, we successfully reject this falsification. This result increases the credibility of our research design.

Data availability

The primary data source is the UNEP DTU CDM/JI Pipeline Analysis and Database (CDM/JI Pipeline) at https://www.cdmpipeline.org/. Additional information, such as ERPA dates, is extracted by Python from CDM documents in PDF format on the UNFCCC CDM projects site (https://cdm.unfccc.int/Projects/projsearch.html). ERPA dates are available on the GitHub from https://github.com/Jiehonglou/Integrating-Sustainable-Development-Goals-into-Climate-Finance-Projects.

Code availability

All data and models are processed in Stata 14.0 and Python. The figures are produced in Python and R. All custom code is available on GitHub from https://github.com/Jiehonglou/Integrating-Sustainable-Development-Goals-into-Climate-Finance-Projects. SDG icon statement: we thank the United Nations SDG Permissions grant the permission of using the United Nations Sustainable Development Goals icons (https://www.un.org/sustainabledevelopment/). The content of this publication has not been approved by the United Nations and does not reflect the views of the United Nations or its officials or Member States.

Received: 15 August 2021; Accepted: 30 May 2022;
Published online: 17 June 2022

References

1. Liu, Z. & Espinosa, P. Tackling climate change to accelerate sustainable development. *Nat. Clim. Change* **9**, 494–496 (2019).
2. Bain, P. G. et al. Co-benefits of addressing climate change can motivate action around the world. *Nat. Clim. Change* **6**, 154–157 (2016).
3. Castro-Nunez, A. Responding to climate change in tropical countries emerging from armed conflicts: harnessing climate finance, peacebuilding, and sustainable. *Food For.* **9**, 621 (2018).
4. Cohen, B., Cowie, A., Babiker, M., Leip, A. & Smith, P. Co-benefits and trade-offs of climate change mitigation actions and the Sustainable Development Goals. *Sustain. Prod. Consum.* **26**, 805–813 (2021).
5. Fujimori, S. et al. A multi-model assessment of food security implications of climate change mitigation. *Nat. Sustain.* **2**, 386–396 (2019).
6. Fuso Nerini, F. et al. Connecting climate action with other Sustainable Development Goals. *Nat. Sustain.* **2**, 674–680 (2019).
7. Horn-Phathanothai, L. & Waskow, D. *Making the Links Real: Connecting Development and Climate Action at the Country Level* https://www.wri.org/insights/making-links-real-connecting-development-and-climate-action-country-level (2016).
8. Iyer, G. et al. Implications of sustainable development considerations for comparability across nationally determined contributions. *Nat. Clim. Change* **8**, 124–129 (2018).
9. Liu, J.-Y. et al. The importance of socioeconomic conditions in mitigating climate change impacts and achieving Sustainable Development Goals. *Environ. Res. Lett.* **16**, 014010 (2021).
10. McCollum, D. L. et al. Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals. *Nat. Energy* **3**, 589–599 (2018).
11. Shindell, D. et al. A climate policy pathway for near- and long-term benefits. *Science* **356**, 493–494 (2017).
12. CPI. *Global Landscape of Climate Finance 2019* https://climatepolicyinitiative.org/publication/global-climate-finance-2019/ (CPI, 2019).
13. UNFCCC. *The Paris Agreement* (UNFCCC, 2015).
14. Karlsson, M., Alfredsson, E. & Westling, N. Climate policy co-benefits: a review. *Clim. Policy* **20**, 292–316 (2020).

15. Driscoll, C. T. et al. US power plant carbon standards and clean air and health co-benefits. *Nat. Clim. Change* **5**, 535–540 (2015).
16. Santucci, L., Puhl, I. & Sinha, M. *Valuing the sustainable development co-benefits of climate change mitigation actions: the case of the waste sector and recommendations for the design of Nationally Appropriate Mitigation Actions (NAMAs)* (ESCAP, 2015).
17. Lewis, E., Pinchot, A. & Christianson, G. "Navigating the Sustainable Investment Landscape." Working Paper. Washington, DC: WorldResources Institute. Available online at http://www.wri.org/publication/sustainable-investment-landscape (2016).
18. Ellis, J., Winkler, H., Corfee-Morlot, J. & Gagnon-Lebrun, F. CDM: taking stock and looking forward. *Energy Policy* **35**, 15–28 (2007).
19. Sirohi, S. CDM: is it a 'win–win' strategy for rural poverty alleviation in India? *Clim. Change* **84**, 91–110 (2007).
20. Disch, D. A comparative analysis of the 'development dividend' of Clean Development Mechanism projects in six host countries. *Clim. Dev.* **2**, 50–64 (2010).
21. Olsen, K. H. & Fenhann, J. Sustainable development benefits of clean development mechanism projects. *Energy Policy* **36**, 2819–2830 (2008).
22. Spalding-Fecher, R. et al. Assessing the Impact of the Clean Development Mechanism. Report commissioned by the High Level Panel on the CDM Policy Dialogue (2012).
23. Subbarao, S. & Lloyd, B. Can the Clean Development Mechanism (CDM) deliver? *Energy Policy* **39**, 1600–1611 (2011).
24. UNFCCC. *Benefits of the Clean Development Mechanism 2012* https://cdm.unfccc.int/about/dev_ben/ABC_2012.pdf (UNFCC, 2012).
25. Watson, C. & Fankhauser, S. *The Clean Development* Mechanism: Too Flexible to Produce Sustainable Development Benefits? (2009).
26. Alexeew, J. et al. An analysis of the relationship between the additionality of CDM projects and their contribution to sustainable development. *Int. Environ. Agreem.: Politics Law Econ.* **10**, 233–248 (2010).
27. Crowe, T. L. The potential of the CDM to deliver pro-poor benefits. *Clim. Policy* **13**, 58–79 (2013).
28. Drupp, M. A. Does the Gold Standard label hold its promise in delivering higher Sustainable Development benefits? A multi-criteria comparison of CDM projects. *Energy Policy* **39**, 1213–1227 (2011).
29. Nussbaumer, P. On the contribution of labelled Certified Emission Reductions to sustainable development: a multi-criteria evaluation of CDM projects. *Energy Policy* **37**, 91–101 (2009).
30. Sutter, C. & Parreño, J. C. Does the current Clean Development Mechanism (CDM) deliver its sustainable development claim? An analysis of officially registered CDM projects. *Clim. Change* **84**, 75–90 (2007).
31. Sutter, C. *Sustainability Check up for CDM Projects: How to Assess the Sustainability of International Projects Under the Kyoto Protocol* (ETH Zurich, 2003).
32. Murata, A. et al. Environmental co-benefits of the promotion of renewable power generation in China and India through clean development mechanisms. *Renew. Energy* **87**, 120–129 (2016).
33. Sun, Q., Xu, B., Wennersten, R. & Brandt, N. Co-benefits of CDM projects and policy implications. *Environ. Econ.* **1**, 78–88 (2010).
34. Zhang, J. & Wang, C. Co-benefits and additionality of the clean development mechanism: an empirical analysis. *J. Environ. Econ. Manag.* **62**, 140–154 (2011).
35. Mori-Clement, Y. Impacts of CDM projects on sustainable development: Improving living standards across Brazilian municipalities? *World Dev.* **113**, 222–236 (2019).
36. World Bank. *Carbon Initiative for Development (Ci-Dev)* (World Bank, 2015).
37. Hultman, N. E., Lou, J. & Hutton, S. A review of community co-benefits of the Clean Development Mechanism (CDM). *Environ. Res. Lett.* https://doi.org/10.1088/1748-9326/ab6396 (2019).
38. McCollum, D. L. et al. Connecting the sustainable development goals by their energy inter-linkages. *Environ. Res. Lett.* **13**, 033006 (2018).
39. IPCC. *Global Warming of 1.5 °C_ chapter5.pdf*. http://report.ipcc.ch/sr15/pdf/sr15_chapter5.pdf (2018).
40. Gold Standard. *Gold Standard Market Report 2018* https://www.goldstandard.org/sites/default/files/market_report_2018.pdf (2019).
41. Gold Standard. *The Real Value of Robust Climate Action: Impact Investment Far Greater than Previously Understood* (Gold Standard, 2014).
42. Parnphumeesup, P. & Kerr, S. A. Classifying carbon credit buyers according to their attitudes towards and involvement in CDM sustainability labels. *Energy Policy* **39**, 6271–6279 (2011).
43. Bustamante, M. et al. Co-benefits, trade-offs, barriers and policies for greenhouse gas mitigation in the agriculture, forestry and other land use (AFOLU) sector. *Glob. Change Biol.* **20**, 3270–3290 (2014).
44. Chhatre, A. et al. Social safeguards and co-benefits in REDD+: a review of the adjacent possible. *Curr. Opin. Environ. Sustain.* **4**, 654–660 (2012).
45. Phelps, J., Webb, E. L. & Adams, W. M. Biodiversity co-benefits of policies to reduce forest-carbon emissions. *Nat. Clim. Change* **2**, 497–503 (2012).
46. UNFCCC. *CDM Methodology Booklet*. 271 (UNFCCC, 2017).
47. Coomes, O. T., Grimard, F., Potvin, C. & Sima, P. The fate of the tropical forest: carbon or cattle? *Ecol. Econ.* **65**, 207–212 (2008).
48. Lasco, R. D., Evangelista, R. S. & Pulhin, F. B. Potential of community-based forest management to mitigate climate change in the Philippines. *Small-scale Forestry* **9**, 429–443 (2010).
49. Minang, P. A., McCall, M. K. & Bressers, H. Th. A. Community capacity for implementing clean development mechanism projects within community forests in Cameroon. *Environ. Manag.* **39**, 615–630 (2007).
50. Thomas, S., Dargusch, P., Harrison, S. & Herbohn, J. Why are there so few afforestation and reforestation Clean Development Mechanism projects? *Land Use Policy* **27**, 880–887 (2010).
51. Neeff, T. & Henders, S. *Guidebook to Markets and Commercialization of Forestry CDM Projects* (CATIE, 2007).
52. World Bank. *BioCarbon Fund Experience: Insights from Afforestation and Reforestation Clean Development Mechanism Projects* (World Bank, 2011).
53. Jindal, R., Swallow, B. & Kerr, J. Forestry-based carbon sequestration projects in Africa: potential benefits and challenges. *Nat. Resour. Forum* **32**, 116–130 (2008).
54. Aggarwal, A. How sustainable are forestry clean development mechanism projects?—A review of the selected projects from India. *Mitig. Adapt. Strateg. Glob. Change* **19**, 73–91 (2014).
55. Paquette, A., Hawryshyn, J., Senikas, A. & Potvin, C. Enrichment planting in secondary forests: a promising clean development mechanism to increase terrestrial carbon sinks. *Ecol. Soc.* **14**, (2009).
56. World Bank. *Insights and Experiences from the BioCarbon Fund Emission Reductions Projects in the Land-Use Sector: An Overview* (World Bank, 2020).
57. Zomer, R. J., Trabucco, A., Bossio, D. A. & Verchot, L. V. Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation. *Agric. Ecosyst. Environ.* **126**, 67–80 (2008).
58. Global CCS Institute. *Developing CCS projects under the Clean Development Mechanism*. http://decarboni.se/sites/default/files/publications/25786/manual-developing-ccs-projects-under-cdm.pdf (2011).
59. Mayrhofer, J. P. & Gupta, J. The science and politics of co-benefits in climate policy. *Environ. Sci. Policy* **57**, 22–30 (2016).
60. IPCC. *Climate Change 2014*: *Synthesis Report*. 151 (IPCC, 2014).
61. World Bank. *CDCF Making an Impact: Carbon Finance Delivers Benefits for the Poor* (World Bank, 2013).
62. UNFCCC. Introduction to Climate Finance | UNFCCC. https://unfccc.int/topics/climate-finance/the-big-picture/introduction-to-climate-finance (2022).
63. World Bank. *Overview of Carbon Offset Programs: Similarities and Differences*. http://documents.worldbank.org/curated/en/891711468309365201/pdf/939450WP0201500ers0385391B00PUBLIC0.pdf (2015).
64. Kollmuss. 'Carbon offsets 101. A primer on the hottest - And trickiest - Topic in climate change', World watch., **20**, 9–14 (2007).
65. Goldstein, A. *Buying in: Taking Stock of the Role of Carbon Offsets in Corporate Carbon Strategies*. https://www.forest-trends.org/wp-content/uploads/imported/buyers-report-2016-final-pdf.pdf (2016).
66. OECD. Official Development Assistance (ODA)—OECD. https://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/official-development-assistance.htm (2022).
67. Conte, M. N. & Kotchen, M. J. Explaining the price of voluntary carbon offsets. *Clim. Change Econ.* **01**, 93–111 (2010).
68. Freeman, A., Herriges, J. & Kling, C. *The Measurement of Environmental and Resource Values: Theory and Methods* (RFF Press, 2014).
69. Garrido, M. M. et al. Methods for constructing and assessing propensity scores. *Health Serv. Res.* **49**, 1701–1720 (2014).
70. Caliendo, M. & Kopeinig, S. Some practical guidance for the implementation of propensity score matching. *J. Econ. Surv.* **22**, 31–72 (2008).
71. Lunt, M. *Propensity Analysis in Stata Revision: 1.1* 30 (2014).
72. Koch, N., Fuss, S., Grosjean, G. & Edenhofer, O. Causes of the EU ETS price drop: recession, CDM, renewable policies or a bit of everything?—New evidence. *Energy Policy* **73**, 676–685 (2014).

Acknowledgements
We thank Dr. Steve Hutton from the World Bank IEG (Independent Evaluation Group) for his vision, guidance, and provide the opportunity to work on the initial co-benefit concept of the carbon finance. We thank the seminar participants at the Center for Global Sustainability of the University of Maryland for their suggestions and recommendations during the preparation of this draft.

Author contributions
J.L. designed the original study and conducted the entire analysis. N.H. provided the guidance on the initial co-benefits project with the methodology design. N.H. and A.P.

contributed to the design of the study and provided guidance during the entire writing. Y.L.Q. encouraged J.L. to investigate the robustness of the empirical analysis.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s43247-022-00468-9.

Correspondence and requests for materials should be addressed to Jiehong Lou.

Peer review information *Communications Earth & Environment* thanks Augusto Castro-Nunez and the other, anonymous, reviewer(s) for their contribution to the peer review of this work. Primary Handling Editors: Nadine Mengis, Heike Langenberg. Peer reviewer reports are available.