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Design Of A Carbon Offset Decision Support Tool For Universities And Small Businesses

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Abstract: A carbon offset allows organizations to compensate for GHG emissions by funding projects that reduce or capture an equivalent amount of CO_2. The Voluntary Carbon Market (VCM) presents financial risks for organizations purchasing offsets, as transactions are non-refundable and may support low-quality projects. This work introduces a decision-support tool that calculates risk scores using a Multi-Attribute Utility Model (MAUM) based on the P.A.V.E.R.+ framework—Permanence, Additionality, Verifiability, Enforceability, Real, and Co-Benefits. The tool helps universities and small businesses evaluate carbon offset quality through structured, data-driven analysis. By assessing risk, environmental effectiveness, and cost, the tool guides users in selecting higher-impact offset portfolios. A university case study showed a 25% improvement in effective GHG reduction, with procurement time reduced by up to 62% and cost by up to 36%. The tool enables informed, strategic purchases that align with sustainability goals, improving the reliability and impact of carbon offset investments.

Keywords: Carbon Offset, Risk Assessment, Voluntary Carbon Market

1. Introduction

To address global warming, there is a need to reduce greenhouse gas (GHG) emissions worldwide (Intergovernmental Panel on Climate Change (IPCC), 2023). The voluntary carbon offset market (VCM) has emerged as a tool for organizations to mitigate their emissions that cannot be eliminated. Carbon offsets are tradable 'rights' or certificates linked to activities that reduce the amount of carbon dioxide (CO_2) or other GHGs in the atmosphere. One carbon offset represents one metric ton of sequestered, absorbed, or transformed CO_2 (Gurgel, 2020). By funding projects like reforestation, renewable energy, and carbon capture through the purchase of carbon offsets, buyers aim to offset hard-to-abate emissions such as air travel and AC/Heating from which GHG production is unavoidable.

However, the VCM faces transparency issues, inconsistent verification standards, and financial risks, particularly for organizations that lack expertise in the VCM. Studies have raised concerns about its effectiveness, a 2023 Nature Communications study found that about 16% of offset projects do not achieve their intended impact, questioning the reliability of carbon offsets in addressing climate change (Kreibich & Hermwille, 2023).

This design describes a decision-support tool to improve risk evaluation and project selection within the VCM. By leveraging analytical frameworks, the tool allows the user to enhance the environmental impact of offset purchases, aiding organizations in making informed investments in high-quality carbon offsets. The following sections explore market challenges and present a structured approach to mitigating risks and improving decision-making in carbon offset investments.

2. Background

In the carbon offset industry, two primary markets exist: the compliance market and the voluntary market. The compliance market, or regulatory market, is established and governed by legally binding frameworks that mandate emissions reductions for specific sectors and industries (Solomon, 2022). In contrast, the VCM operates outside regulatory mandates, allowing companies and organizations to purchase offsets on a discretionary basis (Spilker & Nugent, 2022). The VCM attracts businesses that aim to meet self-imposed sustainability goals.

Registries like American Carbon Registry (ACR), Climate Action Reserve (CAR), Gold Standard (GS), and Verra (VCS) define standards for carbon offset projects, including how they are monitored, reported, verified and ultimately issued credits. These four generate the vast majority of offsets globally within the VCM, with over 9,500 projects producing more than 2.1 billion credits (University of California, Berkeley, n.d.). Projects must follow approved methodologies to become registered, but within these practices, studies have found only 12% of offsets result in real emission reductions (Carbon Brief, 2023).

To address these concerns, an evaluative standard may be used. The P.A.V.E.R.+ framework provides a comprehensive approach to assessing carbon offset integrity by helping buyers navigate risks and ensure that purchased credits deliver real, verifiable climate benefits. The quality of carbon offset projects can be defined in terms of the following criteria:

- **Permanence:** Emission reductions/removals must last in perpetuity.
- **Additional:** Emission reductions must be a result of the offset sale and would not have occurred otherwise.
- **Verifiable:** Offsets must be measurable, monitored overtime, and validated by an independent third party.
- **Enforceable:** Carbon credits must be tracked through creation to retirement to ensure no double counting.
- **Real:** Emission reductions/removals represent genuine decreases in atmospheric GHGs.
- **+(Co-Benefits):** Additional positive outcomes are generated by offset projects that align with the UN Sustainable Development Goals (SDGs).

2.1. Stakeholder Analysis

The VCM functions through a network of diverse stakeholders, each playing a critical role. Buyers, like universities and small businesses, seek affordable and credible carbon offsets, but are forced to spend significant time and resources assessing each project's quality. Registries and validation bodies, such as VCS and GS, maintain market integrity through project certification. Project developers design and implement offset initiatives, balancing environmental impact with financial viability. Brokers and offset marketplaces facilitate transactions, though concerns regarding transparency persist. Local communities demand equitable benefits and long-term sustainability from these projects. Regulatory bodies like the US Environmental Protection Agency (EPA) and United Nations Framework Convention on Climate Change (UNFCCC) provide standards and frameworks to ensure transparent emission accounting and increase credibility of carbon offset projects. Tensions arise from conflicting priorities, such as balancing cost, quality, and environmental impact. The proposed decision-support tool seeks to empower universities and small businesses with relevant quality risk insights that aid their carbon offset selection process with a reduced time and cost incurred.

2.2. As-Is Process

The As-Is process for this work was developed through a combination of research and stakeholder interviews to accurately reflect current practices within the VCM. It is divided into two main components: the creation of offsets and their commercialization. The creation process involves over 30 distinct activities and five stakeholder groups (Project developers, VBBs, Registries, Project stakeholders, and Funding Entities). The commercialization process involves 30 distinct activities and four stakeholder groups (sustainability management, brokers, retail/marketplace, and project developers). As the process of purchasing offsets is the primary focus of this work, the commercialization activities were divided into stages as summarized below.

- **Emission Inventory:** Organizations evaluate their GHG emissions and identify sources that require offsetting.
- **Research:** Enterprises may issue a Request for Proposal (RFP) to solicit carbon offset portfolios from providers, while others conduct independent research by engaging brokers and marketplaces.
- **Portfolio Creation:** Offset providers submit portfolios, but these often reflect seller biases, requiring buyers to conduct thorough reviews based on cost, project type, and location.
- **Review & Vetting:** Buyers perform due diligence to assess project credibility and ensure alignment with sustainability goals.
- **Contracting/Transaction:** Buyers and providers negotiate contract terms, a critical step given financial risks and the lack of safeguards for reversals.

The current process for purchasing carbon offsets is time-consuming, costly, and inconsistent in environmental impact. Procurement can take 3-8 months and cost \$22,000-\$70,000, driven by the need for thorough project vetting and contract negotiations. Without reliable evaluation tools, organizations risk selecting low-quality offsets that fail to deliver meaningful benefits. A decision-support tool that offers clear risk assessments and targeted recommendations can streamline this process, reduce costs, and improve offset effectiveness.

3. Concept of Operations (CONOPS)

The proposed tool serves as a centralized platform for sustainability managers to efficiently research, evaluate, and select carbon offset projects. To support informed and effective decision making, the tool was designed to provide the following core functions:

- **Research Project Information Access:** Users access detailed project data, methodologies, and risk assessments.
- **Preference Setting:** Users customize their P.A.V.E.R.+ criteria and risk tolerance using pairwise analytic hierarchy process (AHP) comparisons.
- **Project Risk Assessment Generation:** The tool generates risk assessments using a Multi-Attribute Utility Model (MAUM) based on the P.A.V.E.R.+ framework.
- **Risk, Cost, and Effectiveness Calculation and Visualization:** The tool calculates and visually summarizes the risk, cost and effective environmental impact for informed decision making.
- **Customized Offset Portfolio Creation:** Users can manually select projects and specify credit quantities to build portfolios, or utilize system-generated recommendations to minimize risk or cost, based on user preference.

4. System Design

4.1. Risk Assessment

The risk assessment module is responsible for evaluating the quality and reliability of carbon offset projects based on the P.A.V.E.R.+ framework. The project assessment is based on data from the Carbon Credit Quality Initiative (CCQI), as well as additional research.

4.1.1. Multi-Attribute Utility Model (MAUM)

Risk scores are calculated using a MAUM, where each P.A.V.E.R.+ criterion is represented by a weighted score. Users define the importance (weights) of each criterion through an interface guided pairwise AHP comparison. Each criterion is evaluated through multiple sub-factors, each with an associated weight and value derived from project details. The risk score for a single criterion is calculated by (1).

$$R_i = w_i \cdot \sum_j (w_{ij} \cdot v_{ij}) \tag{1}$$

Where: w_i = weight assigned to category i, w_{ij} = weight assigned to each attribute j in category i, v_{ij} = score assigned to each attribute j in category i. The total project risk score T_{PR} is then calculated as the sum of all weighted criteria (2).

$$T_{\text{PR}} = R_P + R_A + R_V + R_E + R_R + R_C \tag{2}$$

Where: R_P = Permanence Risk, R_A = Additionality Risk, R_V = Verifiability Risk, R_E = Enforceability Risk, R_R = Real Risk, R_C = Co-Benefits Risk.

4.1.2. Effective Environmental Impact

To support more meaningful decision-making, the system quantifies a projects effective environmental impact, defined as the actual GHG reduction or removal expected per purchased offset credit. Each project is evaluated under the assumption that a risk score of 1 (low risk) in the P.A.V.E.R.+ framework corresponds to 1 $MtCO_2$. Conversely, a risk score of 5 (high risk) is assumed to deliver zero effective benefits. To translate the risk score into an effective impact, a linear normalization is applied to map the 1-5 risk scale to a 1-0 scale (3) left. Using I, the system also calculates the effective cost per $MtCO_2$ (3) right

$$I = \frac{5 - T_{\text{PR}}}{4} \quad , \quad EC = \frac{C}{I} \tag{3}$$

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Where: I = effective impact, T_{PR} = total project risk, EC = effective cost per MtCO_2, C = cost per offset purchase ($/offset). These metrics allow users to prioritize projects not only based on nominal price or risk alone, but on the true cost effectiveness of achieving 1 MtCO_2 of GHG reduction.

4.1.3. Portfolio Risk Score

To evaluate an entire portfolio of offset projects, the system calculates a weighted average risk score based on the quantity of offsets per project:

$$P = \sum_{i=1}^{n} \left(\frac{T_{\text{PR}_i} \cdot Q_i}{Q_T} \right) \tag{5}$$

Where: P = total portfolio risk, T_{PR_i} = total project risk for project i, Q_i = quantity (number of offsets) for project i, Q_T = total quantity of offsets in the portfolio.

4.1.4. Purchase Optimization

The purchase optimization module is responsible for providing the user with purchase recommendations that either minimize risk or minimize cost. After evaluating each project's risk, environmental impact, and cost, the user selects which projects qualify for inclusion in the final purchase portfolio, and specifies the total number of offsets to purchase, Q_T. To promote portfolio diversity and avoid over-concentration in a single project, the system generates $n-1$ optimized portfolio configurations for each set of n eligible projects. Each configuration yields two linearly optimized solutions: one that minimizes portfolio risk (6) left, and one that minimizes total cost (6) right.

$$\min z = \frac{1}{Q_T} \sum_i r_i x_i \quad , \quad minz = \sum_i c_i x_i \tag{6}$$

Where: Q_T = total number of offsets to purchase, r_i = risk score of project i, x_i = number of offset credits purchased from project i, c_i = cost per offset credit for project i, Both objective functions (6) are subject to the following constraints:

$$\sum_i x_i = Q_T \tag{8}$$

$$\sum_i r_i x_i \leq \tau Q_T \tag{9}$$

$$x_i \leq Q_T y_i \tag{10}$$

$$x_i \geq \delta Q_T y_i \tag{11}$$

$$\sum_i y_i = k \tag{12}$$

Where: τ = user-defined risk tolerance, $y_i \in \{0, 1\}$ = binary variable indicating if project i is selected, δ = minimum fraction of Q_T required per selected project, k = number of unique projects in the configuration.

5. Case Study of University Portfolio of Carbon Offsets

The decision support tool was evaluated using carbon offset purchase data from a university profile, referred to as ”hypothetical college.” The portfolio included eight projects, such as clean cookstoves, solar power, and landfill methane capture, aligned with the school's Energy and Carbon Master Plan. Using user-defined weights for P.A.V.E.R.+ criteria, the tool calculated project risk scores.

As shown in Figure 1, the risk vs. cost analysis (top left) revealed that nature-based projects (e.g. VCS1477, CAR1648) were the most costly and risky, while landfill and solar projects (e.g. GS7467, GS1214) offered lower risk and cost. The risk breakdown (top right) highlighted the ”Real” factor as the primary contributor, driven by its high user wieghting. Environmental effectiveness (bottom left) showed solar and landfill projects delivered the most GHG reduction per offset, while nature-based projects underperformed. The cost-efficiency view (bottom right) indicated that even moderate impact projects like VCS1902 could be more cost-effective due to lower prices.

Overall, the tool outputs enable sustainability managers to weigh trade-offs between cost, risk, and environmental impact, improving the quality and value of carbon offset portfolios.

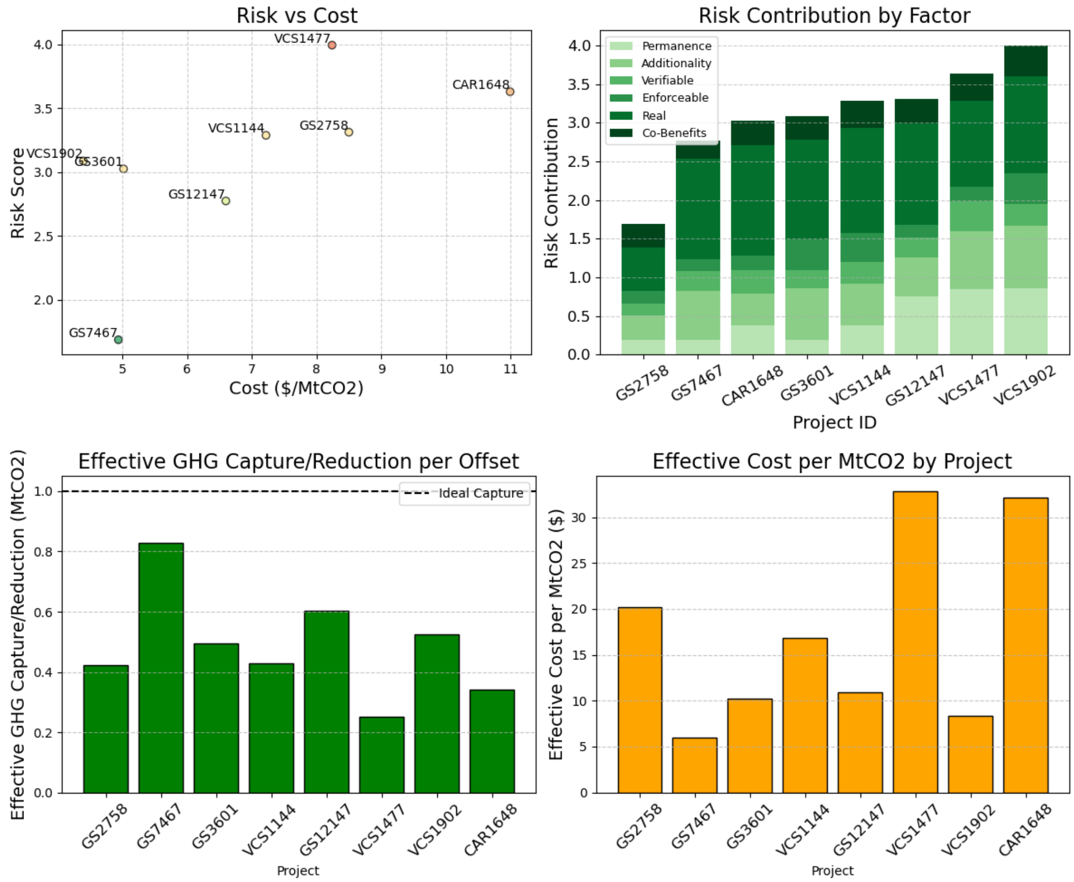

Figure 1: Analysis of Hypothetical College Offset Projects. Top: Risk vs. Cost (left) and Project Risk Breakdown (right). Bottom: Effective GHG Capture/Reduction (left) and Effective Cost per $MtCO_2$ (right).

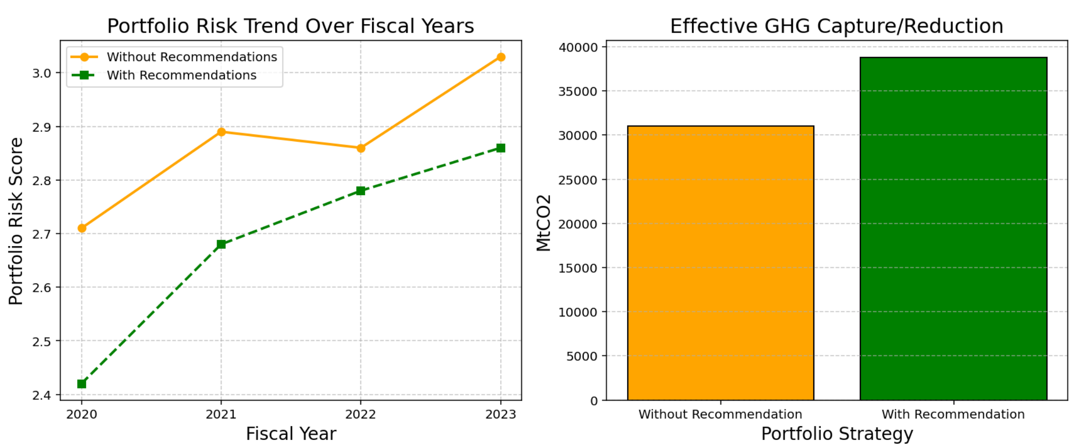

Figure 2: Portfolio Risk of Hypothetical College for Each FY (left). Effective GHG Capture/Reduction of Entire Portfolio (right).

To evaluate performance, two offset portfolios were created for the hypothetical college with equal total offset quantities. One reflected historical purchases (without recommendation), while the other used optimized recommendations from the decision-support tool, Table 1. For accuracy the tool was limited to projects available during each fiscal year. As shown in Figure 2, the recommended portfolio consistently outperformed the historical one, achieving a lower final risk score (2.86 vs. 3.03) and a 25% improvement in effective GHG reduction. Additionally, the optimized portfolio reduced overall costs by approximately $25,000.

Table 1: Offsets Purchased With and Without Recommendation by Fiscal Year

Project ID	**Project Type**	**Cost Per Offset ($)**	**Without Recommendation**				**With Recommendation**			
			FY20	FY21	FY22	FY23	FY20	FY21	FY22	FY23
GS2758	Efficient Cookstoves	8.50	8,345	5,000	178	–	–	3,761	4,458	–
GS3601	Household Biodigesters	5.02	5,216	7,539	12,344	–	5,215	8,778	4,458	–
GS7467	Solar Photovoltaic Power	4.94	5,216	–	–	–	10,433	–	–	–
VCS1144	Household Biodigesters	7.22	2,086	–	–	–	5,215	–	–	–
GS1247	Landfill Gas Utilization	6.60	–	–	3,977	1,730	8,917	–	8,917	9,608
VCS1477	Avoided Planned Deforestation	8.24	–	–	1,334	–	–	–	–	–
CAR1648	Improved Forest Management	10.99	–	–	–	10,000	–	–	–	4,804
VCS1902	Landfill Gas Utilization	4.40	–	–	–	7,486	–	–	–	4,804
		Total Purchased	70,451				70,451			
		Total Cost	$473,267.20				$447,875.40			

6. Business Plan

The tool's business plan includes a tiered annual subscription: $5,000 for Tier 1 with basic risk analysis, and $15,000 for Tier 2, a premier version with Tier 1 benefits plus purchase optimization. Targeting 8,5000 universities and small businesses, the model assumes a 1% market capture in year one with 2% annual groth. Based on these assumptions, projected five-year revenue is $11.2 million, with a 1,500% return on investment and a break-even point in year three. Initial investment is $750,000, with annual operating costs of $200,000.

7. Conclusion

This paper presents a novel decision-support tool designed to enhance transparency, minimize risk, and optimize the selection of carbon offset projects for universities and small businesses. Using a MAUM based on the P.A.V.E.R.+ framework, the tool delivers tailored risk assessments aligned with user-defined sustainability priorities.

A case study showed the tool improved effective GHG reductions by 25%, cut procurement time by up to 62%, and reduced costs by up to 36%. These results highlight its potential to improve offset decision-making and support the integrity of the VCM. The tool also offers a scalable business model through a tiered subscription, making it accessible to a broad user base. By enabling data-driven, value-aligned purchases, the tool helps organizations meet climate goals more effectively and confidently.

References

Carbon Brief. (2023). *Interactive: How 'high quality' are the world's carbon offsets?* `https://interactive.carbonbrief.org/carbon-offsets-2023/index.html`.

Gurgel, A. (2020, September). *Carbon offsets.* `https://climate.mit.edu/explainers/carbon-offsets`.

Intergovernmental Panel on Climate Change (IPCC). (2023). *Ar6 synthesis report: Climate change 2023 – longer report.* `https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_LongerReport.pdf`.

Kreibich, N., & Hermwille, L. (2023). Systematic assessment of the achieved emission reductions of carbon offset projects. *Nature Communications*, *14*, Article 53645. Retrieved from `https://www.nature.com/articles/s41467-024-53645-z` doi: 10.1038/s41467-024-53645-z

Solomon, A. (2022, April). *A guide to compliance carbon credit markets.* `https://carboncredits.com/a-guide-to-compliance-carbon-credit-markets/`.

Spilker, G., & Nugent, N. (2022). Voluntary carbon market derivatives: Growth, innovation, & usage. *Borsa Istanbul Review*, *22*(2). Retrieved from `https://doi.org/10.1016/j.bir.2022.11.008` doi: 10.1016/j.bir.2022.11.008

University of California, Berkeley. (n.d.). *Berkeley carbon trading project.* `https://gspp.berkeley.edu/research-and-impact/centers/cepp/projects/berkeley-carbon-trading-project`.