

Where Should the Trees Go? Judging Three Carbon-Capture Plans

Learning target: I can evaluate competing reforestation plans against criteria and constraints, calculate how much carbon each would capture for its cost, and design and justify a plan that uses the best features of each.

Transfer and design

About 55 min

Pairs

MS-ETS1-2 · assesses

MS-ETS1-3 · practice

MS-ETS1-1 · practice

MS-LS2-3 · supports

engineering design

data analysis

writing

Standards connections

MS-ETS1-2 (assesses): Students score three candidate sites against stated criteria and constraints using a decision matrix and per-dollar calculations, then choose. That systematic comparison is the PE as written.

MS-ETS1-3 (practice): After comparing, students combine the best characteristics of two sites into a new plan. The data come from a table rather than from tests students ran, so this builds toward the PE rather than meeting it.

MS-ETS1-1 (practice): Students must restate the county's goals as testable criteria and identify which limits are constraints, including impacts on the people who farm one of the sites.

MS-LS2-3 (supports): The whole challenge rests on the carbon-cycle idea that photosynthesis moves carbon from the air into a living reservoir, and that burning or decay returns it. The science is applied here, not modeled.

Purpose: extend · **Time:** about 55 minutes · **Format:** pairs

Answers with reasoning

The county's brief — 'We have \$120,000, to be spent once, within the next year. We want the trees to remove as much carbon dioxide from the air as possible and keep that carbon stored for at least 30 years. We need at least 250 tons of carbon captured per year once the trees are established. We will not take land that people are living on or farming. Planting crews must be able to reach the site.'

The three candidate sites (teaching scenario, not real places)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Site	Carbon captured per hectare per year once established (tons)	Cost to plant one hectare	Land available (hectares)	Road access	People on the land	Wildfire risk	Note
A: River valley	6.0	\$1,800	30 unused; another 60 is farmed	Yes, paved	40 families farm the 60 ha	Low (wet)	Fast-growing trees; occasional floods but trees tolerate them
B: Dry hills	1.5	\$600	300	Yes, gravel	None	High: brush fire every 10 to 15 years	Slow-growing drought-tolerant trees
C: Remote coast	4.0	\$2,400	80	No road; crews walk in 2 hours	None	Low (foggy)	Without a road, crews can plant at most 25 ha in one year

Carbon figures are tons of carbon stored in new wood, roots and leaves per hectare per year after the trees are established. All values are invented for this exercise.

Part A: Define the problem precisely

- Sort each statement from the brief as a **criterion** (a goal the plan is judged on) or a **constraint** (a limit the plan must stay within), and write how you would test it.

Answer: Captures at least 250 tons per year: criterion; test by calculating tons per year from hectares × rate. Stored for 30 years: criterion; test by checking wildfire, flood and land-use risks over 30 years. Cost no more than \$120,000: constraint; test by adding up hectares × cost per hectare. No land lived on or farmed: constraint; test by checking the 'people on the land' column and using only unused hectares. Reachable and planted within a year: constraint; test by checking road access and the yearly planting limit.

Why: Criteria are the goals a plan is scored on (how much, how long); constraints are limits that rule plans in or out (money, land, access, time). Each test must be checkable with the table.

Also acceptable: Some engineers treat the 250-ton line as a constraint (a minimum that must be met). Accept that with the reasoning that it is a pass/fail threshold.

- Each statement sorted correctly
- Each has a concrete test

2. The brief says 'as much carbon dioxide as possible.' Why is that phrase hard to use for judging plans, and how does the 250-ton line help?

Answer: 'As much as possible' has no number, so two plans cannot be compared against it and no plan can fail it. The 250-ton line turns the goal into a test: a plan either reaches 250 tons per year or it does not, and plans above the line can then be ranked by how far above it they are.

Why: This is the precision idea in MS-ETS1-1: criteria need numbers to be usable.

Also acceptable: Accept 'you can't tell if you succeeded' as the problem.

- Says the phrase has no measurable target
- Says the 250-ton line makes the criterion testable

Part B: Calculate what each site can do alone

3. Fill in the table for each site **used alone** with the whole budget. Remember: Site A has only 30 unused hectares, and Site C can plant at most 25 ha in a year. Show one full line of work below the table.

Answer: Site A: $\$120,000 \div \$1,800 = 66.7$ ha affordable, but only 30 ha are unused, so 30 ha; $30 \times 6.0 = 180$ tons per year; cost $30 \times \$1,800 = \$54,000$; $180 \div \$54,000 \times 1,000 = 3.3$ kg per dollar spent (or 1.5 kg per dollar of the full budget). Site B: $\$120,000 \div \$600 = 200$ ha, within the 300 available, so 200 ha; $200 \times 1.5 = 300$ tons per year; $300 \div \$120,000 \times 1,000 = 2.5$ kg per dollar. Site C: $\$120,000 \div \$2,400 = 50$ ha, within the 80 available, but the one-year limit caps planting at 25 ha; $25 \times 4.0 = 100$ tons per year; cost $25 \times \$2,400 = \$60,000$; $100 \div \$60,000 \times 1,000 = 1.7$ kg per dollar spent (0.83 kg per dollar of the full budget).

Why: The key traps are the land cap at A and the one-year planting cap at C. Kilograms per dollar should be computed on the money actually spent; accept the full-budget version if the student says which they used.

Also acceptable: Accept 66.7 or 67 ha in the first column for A and 50 ha for C, as long as the second column applies the caps.

4. Which site gives the most carbon per dollar? Which gives the most carbon per year on its own? Explain why those are not the same site.

Answer: Most carbon per dollar: Site A (3.3 kg per dollar), because its trees grow four times faster than B's while costing only three times as much per hectare. Most carbon per year alone: Site B (300 tons), because it has enough land to absorb the whole budget, while A runs out of usable land after \$54,000. The best rate and the best total differ because A is limited by land, not by money.

Why: Students should see that a per-dollar rate and a total depend on different limits.

Also acceptable: None.

- A for per-dollar, B for total, with numbers
- Explains the land limit at A

Part C: Score the sites

5. Write **yes**, **no** or **at risk** in each cell, using your q3 numbers and the site table. Below the table, explain every 'at risk' you wrote.

Answer: Site A alone: 250 tons? no (180). Stored 30 years? yes (low fire risk; floods tolerated). Within budget? yes (\$54,000). No people displaced? yes (only the 30 unused ha). Reachable in a year? yes. Site B alone: 250 tons? yes (300). Stored 30 years? at risk (a fire every 10 to 15 years is almost certain to burn within 30 years, returning much of the carbon to the air). Within budget? yes. No people? yes. Reachable? yes. Site C alone: 250 tons? no (100). Stored 30 years? yes. Within budget? yes (\$60,000). No people? yes. Reachable in a year? at risk or no (no road; only 25 ha plantable in a year, and crews walk two hours each way).

Why: The matrix shows that no single site passes everything cleanly: A and C fail the 250-ton criterion, B passes it but is at risk on storage.

Also acceptable: Accept 'no' for C's reachability if the student argues the two-hour walk makes planting impractical; accept 'yes' if they argue 25 ha was planted within the year.

- Matrix completed with q3 numbers
- Each 'at risk' explained below the table

6. Site B is cheap and has the most land, but a brush fire burns the hills every 10 to 15 years. Explain what a fire would do to the carbon the trees had captured and which criterion that threatens.

Answer: A fire is combustion: the carbon stored in the trees' wood and leaves would combine with oxygen and return to the air as carbon dioxide within hours, undoing years of capture. That threatens the criterion that the carbon stay stored for at least 30 years. With a fire every 10 to 15 years, Site B's trees would very likely burn at least once in 30 years.

Why: Students apply the combustion arrow of the carbon cycle to the permanence criterion.

Also acceptable: Accept 'the carbon goes back into the atmosphere' with the criterion named.

- Names combustion returning carbon dioxide to the air
- Names the 30-year storage criterion

Part D: Design and defend your plan

7. Design your plan. It may use one site or combine sites. State how many hectares you would plant at each site, the cost of each part, the total cost, and the total carbon captured per year. Show the calculations.

Answer: Model plan (one strong answer): plant all 30 unused ha at Site A ($30 \times \$1,800 = \$54,000$; $30 \times 6.0 = 180$ tons per year), then spend the remaining \$66,000 at Site B ($\$66,000 \div \$600 = 110$ ha; $110 \times 1.5 = 165$ tons per year). Total cost \$120,000; total $180 + 165 = 345$ tons per year. Alternative plans: A plus C (30 ha at A for \$54,000 and 25 ha at C for \$60,000 gives $180 + 100 = 280$ tons per year for \$114,000, meeting 250 tons with no fire risk); B alone (300 tons per year, at risk from fire).

Why: The A-plus-B combination maximizes tons per year (345) within every constraint; A-plus-C trades 65 tons per year for much lower fire risk. Either is a defensible design; the calculations must be shown and correct.

Also acceptable: Any plan with correct arithmetic that satisfies all constraints and reaches 250 tons per year earns full credit on this item; the quality of the reasoning is scored in q8.

- Hectares, cost and tons stated for each part
- Total cost within \$120,000
- Total tons per year correct for the stated hectares
- Plan respects the land and one-year caps

8. Justify your plan to the board. Explain how it meets every criterion and constraint, which plan it beats and by how much, and what trade-off you accepted. If part of your plan is 'at risk' on any criterion, say what you would do about it.

Answer: Model justification for A plus B: It meets the 250-ton criterion with 345 tons per year, 45 more than B alone and 165 more than A alone. It stays within \$120,000 exactly, uses only Site A's unused 30 ha so no farm family is displaced, and both sites have roads so planting finishes within a year. The trade-off accepted: 110 of the hectares are at Site B, where fire is likely within 30 years, so about 165 of the 345 tons per year are at risk; the 180 tons per year at Site A are secure. To manage the risk, the plan could set aside part of the budget for firebreaks at B, or choose A plus C instead (280 tons per year, all low-risk, \$114,000) if the board values certainty over the extra 65 tons. Model justification for A plus C: it meets all five tests with no 'at risk' cells, captures 280 tons per year, and leaves \$6,000 for maintenance; the trade-off is 65 fewer tons per year than A plus B and a hard planting season at C.

Why: Full credit requires every criterion and constraint addressed with a number or a check, a comparison with at least one other plan, and an honest trade-off with a response to it. A student who chooses B alone must address the fire risk directly to earn credit.

Also acceptable: A student who argues for A plus C on permanence grounds is making a strong engineering argument and should not lose credit for capturing fewer tons.

- Every criterion and constraint addressed
- Comparison with at least one rival plan using numbers
- Trade-off named and a response to it given

9. Draw a simple carbon model of your plan: the air, the new forest, and the arrows between them, labeled with the process. Add a third box and arrow showing what would happen to the stored carbon if the forest burned or was cut and left to rot.

Answer: Two boxes, 'Carbon dioxide in the air' and 'New forest (wood, roots, leaves)', with an arrow from air to forest labeled 'photosynthesis' (and optionally a smaller arrow back labeled 'cellular respiration'). A third box, 'Burned or rotting forest', with an arrow from forest to it and an arrow from it back to the air labeled 'combustion' or 'decomposition by decomposers (cellular respiration)', showing the stored carbon returning as carbon dioxide.

Why: The drawing checks that students see reforestation as moving carbon between reservoirs and that the storage is reversible.

Also acceptable: A model that routes rotting through 'decomposers' as a box is fine.

- Air and forest boxes with a photosynthesis arrow
- A return route labeled combustion or decomposition

10. Name one piece of information not in the table that you would want before the board votes, and explain how it could change your decision.

Answer: Examples: how often Site A floods badly enough to kill young trees (could make A's storage 'at risk'); whether the county could pay for a road or trail at C, which would raise its yearly planting limit; what the trees at B would cost to protect with firebreaks; how long the trees take to become 'established' at each site, since the 250-ton rate applies only after that; whether the farm families at A would accept trees on the unused 30 ha near their fields; which tree species are native to each site, since non-native plantings may do poorly or harm the ecosystem.

Why: Any missing fact that affects a criterion or constraint, with an explanation of how it could change the plan, earns credit.

Also acceptable: Accept questions about cost of maintenance or water availability.

- A specific missing fact
- A clear link to a criterion or constraint and to the decision

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
Defining criteria and constraints	All five statements sorted correctly with a concrete, checkable test for each; explains why a numeric criterion is needed.	Four of five sorted correctly with tests; the numeric-criterion idea is stated briefly.	Criteria and constraints mixed up in two or more places, or tests are vague ('check if it works').	Statements copied without sorting or tests.
Calculations	Hectares, tons per year and kg per dollar correct for all three sites, with the land cap at A and the one-year cap at C applied and work shown.	Calculations correct except one cap missed or one arithmetic slip, with work shown.	Several errors or caps ignored, but the method is visible.	Numbers missing or unrelated to the table.

Systematic evaluation	Scoring matrix complete and accurate; every 'at risk' explained with the carbon cycle (combustion returns carbon to the air); clearly identifies that no single site passes cleanly.	Matrix complete with one error or one unexplained 'at risk'.	Matrix partly complete; sites judged by one factor only (for example, cheapest wins).	No systematic comparison.
Design and justification	Plan combines sites to meet all criteria and constraints with correct totals; justification addresses each test with numbers, compares with a rival plan, names a trade-off and responds to it; carbon model drawn with the return route.	Plan meets all tests with correct totals; justification addresses most tests; trade-off named but not addressed.	Plan meets the budget but misses a criterion or constraint, or justification restates the plan without reasons.	No plan, or a plan that violates a constraint without noticing.

Teacher notes

All site data are invented; the carbon-capture rates (1.5 to 6 tons of carbon per hectare per year) are in the range reported for slow dryland plantings up to fast-growing plantations, and the planting costs are plausible but not from any real program. The intended discovery is that no single site passes all five tests: A and C fall short of 250 tons per year and B is at risk from fire, so the best designs combine sites (A plus B for 345 tons per year, or A plus C for 280 tons per year with lower risk). Both are defensible; grade the reasoning, not the choice. Make sure students apply both caps (30 usable hectares at A; 25 plantable hectares per year at C) before computing totals, since skipping them changes the ranking. The permanence criterion is the real-world lesson: carbon stored in trees returns to the air if the forest burns, is cleared or decays, so 'tons captured' and 'tons still stored in 30 years' are different numbers. If time is short, assign Part A as homework the night before.

Scaffold offered to students: One site at a time, four steps

For each site: (1) divide \$120,000 by the cost per hectare to get the hectares the money could buy; (2) compare that with the hectares the site actually allows and take the smaller number; (3) multiply the hectares by the tons per hectare per year to get tons per year; (4) divide the tons per year by \$120,000 (or by the money actually spent) and multiply by 1,000 to get kilograms of carbon per dollar. Example with made-up numbers: $\$120,000 \div \$1,000 = 120$ ha; site allows 50, so use 50; 50×2 tons = 100 tons per year; $100 \div 120,000 \times 1,000 = 0.83$ kg per dollar.

Extension: Buy down the fire risk

Suppose a firebreak and thinning program at Site B costs \$150 per hectare and cuts the chance of losing the trees to fire in any 30-year period from about 90 percent to about 20 percent. Rework your plan with this option: recompute the hectares and tons, and decide whether the extra cost is worth it. Then write a short memo to the board explaining how you weighed 'tons captured' against 'tons likely to still be stored in 30 years,' and why the second number is the one the brief really asks for.