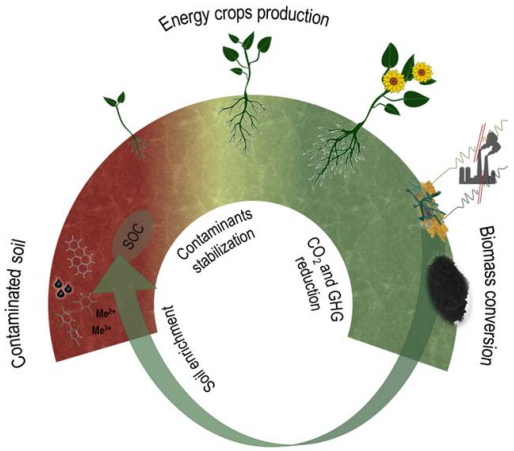
ReNBES Decision Guide: Phytomanagement of Contaminated Land with Annual Energy Crops

A practical guide for public authorities and site managers



Assess whether a site is suitable!

Decide what to test in a pilot!

Plan how to use the harvest!

The ReNBES approach links annual energy crops with biomass use and, where the material is suitable, biochar production and return to the soil.

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Could Phytomanagement Work at Your Site

Use the information you already have to decide whether energy crop phytomanagement merits a closer look. If a key answer is uncertain, record what evidence you need and who can obtain it.

Question	What to check	What the answer means
What should change at the site?	Current and planned land use, affected people or ecosystems, and the exposure route that needs to be controlled.	Define the outcome and the area it applies to. Clarify land use and the exposure route before selecting a measure.
How quickly must the risk be reduced?	Urgent exposure, ongoing releases, sensitive receptors and deadlines for site reuse.	Address urgent risks first. Consider whether crops could complement a faster measure elsewhere on the site.
Can crops influence the relevant exposure route?	Contaminants, their distribution and depth, and whether soil cover or roots can affect the route.	Investigate the link if uncertain. Where vegetation offers little control over the main route, consider other measures.
Can crops establish and be managed?	Soil or sediment conditions, signs of phytotoxicity, water availability, access and land availability.	Where establishment is plausible, consider a small trial. Resolve major site constraints before committing to planting.
Can the harvest be managed?	An operator, a potential destination and practical arrangements for handling the biomass.	Confirm a feasible route before committing to a pilot. Include the cost of treatment or disposal if use remains uncertain.

Choose the next step

Proceed to detailed assessment if the approach appears feasible. Collect targeted evidence where answers are missing. Consider another or combined intervention where site conditions or the required timeframe rules out relying on crops alone.

What Phytomanagement Does

Phytomanagement uses plants and associated soil management to reduce contaminant risks while supporting a planned use of the site. ReNBES focuses on annual energy crops, with a planned destination for the harvested biomass.

Mechanism	What it can achieve	What the Pilot Should Show
Phytostabilisation	Vegetation and root-zone processes can limit contaminant mobility or reduce exposure through erosion, dust or leaching.	Does the planting reduce contaminant movement along the main exposure pathway? For example, compare the amount of contaminant carried in runoff from planted plots and comparable plots without the intervention.
Phytoextraction	Plants take up contaminants into harvestable tissue. Harvesting removes the contaminant mass present in that tissue.	How much of the target contaminant leaves the site in the harvested crop each year? Report the amount per hectare and assess whether that rate can meet the site objective within the available time.
Plant-assisted degradation of organic contaminants	Plants and microorganisms in the root zone can contribute to the breakdown of some organic contaminants.	Measure the target contaminant in soil before and after the pilot. Compare the change in planted and unplanted plots under the same conditions, including any soil amendments. Where relevant breakdown products are known, measure them in the soil as well. Before attributing a decrease to degradation, check whether the contaminant could have moved elsewhere or become harder to extract from the soil.

More than one process can contribute

The same crop can stabilise part of a contaminant in the root zone while taking up a fraction into harvestable tissue. Set the desired outcome first, then measure the contribution of each relevant process. In mixed contamination, a planting system may help manage the mobility of metals and influence degradation of some organic contaminants.

Characterise the Site Before Planting

Use the site history and a field visit to identify likely contamination sources, areas with different soil or fill materials, and routes by which contaminants could reach people, water or ecosystems. Ask the technical team for a sampling map and a separate interpretation for each area that may require different management.

What to assess	What to measure or record?	How to use the results?
Extent and depth of contamination	Map the site boundary, suspected sources, hotspots, drainage routes and nearby receptors. Record the coordinates and depth of each sample. Sample the surface soil and deeper layers separately where contamination may extend below the expected root zone. Sample suspected hotspots separately.	Define which areas can be considered for planting and which need further investigation or a separate intervention.
Total contaminant concentrations	Select the analytes from the site history. These may include metals and metalloids, petroleum hydrocarbons or specific organic compounds. Report concentrations by area and depth and compare them with applicable values for the material and intended land use.	Identify the contaminants that require attention and where additional investigation is needed.
Contaminant mobility and potential plant availability	For priority contaminants, select a test that matches the question. Use leaching tests where transport to water is the concern. Where crop uptake is relevant, use a suitable extractable-fraction test or measure uptake in a pot trial with the proposed crop. Record the method alongside the result.	Assess whether contaminants could move off site or enter the harvest. Use this evidence to select what the pilot should monitor.

What to assess	What to measure or record?	How to use the results?
Soil pH and salinity	Measure pH and electrical conductivity and record both methods. As agronomic reference points, published guidance gives pH 6.0–7.0 for oilseed rape and a target of 6.0 for sorghum. Interpret these values using the laboratory's pH method and local crop advice.	Where acidity limits crop establishment, request a lime requirement test. Consider agricultural limestone, or dolomitic limestone if the soil also needs magnesium. If salinity is elevated, assess crop tolerance and drainage before selecting an amendment.
Organic matter, nutrients and rooting conditions	Measure organic matter or organic carbon, soil texture, mineral nitrogen, plant-available phosphorus and potassium, and magnesium where relevant. Check for compaction, poor drainage and restricted rooting depth.	If low organic matter is associated with poor structure or water retention, test a suitable mature compost or characterised biochar. Correct nutrient deficiencies using soil-test-based fertiliser recommendations. Check amendment quality and its effect on contaminant mobility before field application.
Phytotoxicity to the proposed crop	If establishment is uncertain, grow the proposed crop in soil from each priority area and in a suitable reference soil. Record emergence, early biomass and visible injury. If an amendment is proposed, compare amended and unamended site soil.	Treat poor establishment or sustained growth suppression as a reason to diagnose the cause before planting at scale. Proceed to a field pilot where the crop establishes and the main constraints can be managed.

Before moving to pilot design, document the areas suitable for planting, the constraints that need correction, and the contaminants or exposure pathways that the pilot must address.

PILOT DESIGN

Set the Site Objective

Use the site characterisation to select a representative area for the pilot. Define what the pilot must demonstrate before the approach can be applied more widely.

Design decision	What to document before planting
Select the pilot area	Choose a zone representative of the conditions where phytomanagement could be applied. Record the plot boundaries, soil or sediment type, contaminant levels and any rooting or drainage constraints. Assess hotspots separately if they require different management.
Define a measurable objective	State what needs to improve and how it will be measured. For example, if the concern is contaminant leaching, measure the amount released in a leaching test. If the objective includes removal through harvest, estimate the contaminant mass removed per hectare from dry biomass yield and tissue concentrations.
Choose the crop and any amendment	Select a crop, such as oilseed rape, forage sorghum or other energy crops, based on the site assessment and any pot trial results. If an amendment is needed, record which constraint it is intended to address and the application rate to be tested.
Set up comparison plots	Use comparable, replicated plots where feasible. To assess the added value of biochar, compare the same crop grown with and without biochar under otherwise equivalent management. If the question is what planting itself contributes, include a comparable unplanted treatment with the same amendment status.
Agree when to continue, adapt or stop	Before planting, agree on the minimum acceptable crop establishment and the improvement required for the site objective. Set a review date and identify the findings that would trigger a change, such as persistent poor establishment or increased contaminant mobility.

Record the selected treatments, sampling dates, responsibilities and decision criteria in the pilot plan.

Measure Performance and Review the Pilot

Measure baseline conditions before treatment before soving and after harvesting. Repeat measurements at comparable locations and depths, and record sampling dates, weather, site operations and crop performance.

If the objective is to	Track	Interpretation
Reduce contaminant mobility or exposure	Relevant measures such as leachate, pore water, runoff, dust or an operationally defined available fraction.	Link the indicator to the exposure route. Review whether the change is sustained and whether another route has become more important.
Remove contaminants through harvest	Dry yield per hectare and contaminant concentration in each harvested fraction.	Report mass removed per hectare. Sum the measured contributions of the individual fractions and harvests.
Support degradation of organic contaminants	Parent compounds and relevant products, with comparable plots or other lines of evidence.	Separate evidence for degradation from effects of sorption, dilution or movement.
Maintain vegetation and manage biomass	Crop establishment, cover, harvest yield and contaminant concentrations in the fractions intended for use.	Review whether the crop meets site and biomass acceptance criteria.

Review at the end of each growing season

Compare results with the agreed criteria and document uncertainty, seasonal variation and any changes in exposure. Use the findings to continue the pilot, adjust its design or assess readiness for wider application.

Plan the Use of Harvested Biomass

Identify potential destinations before sowing. Confirm the destination of each harvested fraction after sampling and checking the requirements of the receiving operator.

Possible destination	Check before allocating a fraction
Pyrolysis for biochar	Confirm feedstock origin, acceptance, contaminant concentrations and moisture. Agree how batches will be recorded and which intended uses the biochar will be tested for.
Energy recovery or another use	Confirm whether the operator can accept the material and whether a price is available for the expected quality and quantity. Include handling and transport costs.
Treatment or disposal	Identify an appropriate route and budget for storage, transport and handling where use is unavailable or a fraction fails acceptance checks.

Keep fractions separate where they differ

For oilseed rape, assess seed and harvest residues separately if they are destined for different uses. For sorghum, distinguish cuts or lots where yield, moisture or contaminant concentrations differ. Keep records of the plot, harvest date, wet mass, moisture and sampling results.

Allocate the harvest in the budget

Assign a quantity to each route. A fraction sent to pyrolysis has a processing cost and may displace potential sales revenue. Base revenue on the quantity an operator is likely to accept, at the agreed moisture and quality.

Produce and Characterise Biochar

Choose the intended application before producing biochar. Feedstock selection, process conditions and the tests required for the finished material depend on that application.

Check	Evidence to obtain
Feedstock and traceability	Document species, harvested fraction, source plot, batch size and analyses. Check the current EBC positive list and intended class if pursuing EBC conformity and verify the receiving facility's requirements.
Production and process streams	Record temperature, residence time and feedstock preparation. Identify how the operator controls emissions and handles residues and other process streams.
Finished batch	Sample the batch representatively. Review relevant contaminants and use-specific properties. For soil, consider pH, salinity and leachability. For water treatment, verify performance in the target water.
Eligibility for the intended use	Document test results, applicable limits and operator acceptance. Where EBC certification is sought, check the applicable certification and process requirements as well as laboratory values.

Follow the contaminants through the process

Pyrolysis can concentrate some metals in the solid fraction. Consider partitioning across the biochar and other streams when designing tests and controls. Recheck batch suitability when the feedstock or process changes materially.

Choose an End Use for Biochar

Use the batch results to assess each route independently. When a batch is unsuitable for soil application, record the reason and check whether that issue also limits other uses.

Route	Evidence needed	Decision
Return to the managed site	Check feedstock and batch quality against the relevant EBC criteria, applicable rules and a site trial. Verify the dose, effects on plant growth and leaching, and the response of target contaminants.	Apply only where site evidence and applicable requirements support it. Monitor the amended plots against the agreed objective. If biochar is returned to the site, record the amount of each target contaminant returned with it and account for this when estimating net removal
Use as a sorbent in water treatment	Test sorption and leaching in the target water and assess performance under realistic operating conditions. Identify a route for spent sorbent.	Use only if the operator accepts the material and the evidence supports the intended treatment and handling of spent media.
Energy recovery or another managed route	Confirm acceptance and applicable requirements for the material, including emissions and residues where relevant.	Use an appropriate facility if acceptance is confirmed. Arrange treatment or disposal if no proposed use is viable.

Verify the effect in soil

Biochar may reduce contaminant mobility and, in some settings, support degradation of susceptible organic contaminants. Check these effects separately. Sorption can reduce availability even when the contaminant persists. Apply EBC as a voluntary quality and certification framework alongside site-specific assessment and applicable law.

Compare Costs and Expected Outcomes

Compare options against the required risk reduction and the time available. Use a common cost basis and state the area, soil volume where relevant, management horizon, price year and discount rate.

Include in the comparison	How to estimate it
Implementation and monitoring	Estimate establishment, annual crop management, harvest, analyses, oversight and longer-term monitoring. Add any time-related land costs where relevant.
Biomass and biochar routes	Include storage, transport, conversion, testing and residue handling. Use expected sales from accepted material, based on its quality and moisture. Count a biomass fraction once.
Net cost and uncertainty	Discount costs and revenues to a common year. Test sensitivity to yield, sale price, monitoring frequency, management duration and the availability of a viable outlet.
Expected outcome and timing	State what each option achieves and when. Distinguish removal of affected material, reduced mobility or exposure, and restoration of land function.

Illustrative estimates from ReNBES

Estimated net present cost for phytomanagement was about €23,100/ha over five years and €45,300/ha over ten years. Monitoring was the largest direct cost, and biomass sales offset about 13–14% of discounted direct costs. Base estimates were €1.35 million/ha for excavation and landfill disposal and €900,000/ha for solidification/stabilisation. The estimates reflect the report's assumptions, and the interventions deliver different outcomes. In a combined 20-year sensitivity case with no biomass sales and doubled monitoring costs, the estimated net present cost was about €143,400/ha. The modelled periods are budgeting horizons. Verify local costs and the time needed to meet the site objective.

Legal Framework and Implementation Barriers

Before committing funds or expanding the pilot, confirm who is responsible for the site, which approvals are needed and where the harvested materials can go. Record each unresolved issue, who will address it and whether it affects the schedule or budget.

Issue	What to confirm before proceeding
Site responsibility and remediation approval	Identify the party responsible for the site and confirm access for planting, sampling and monitoring. Check whether the proposed works require an approved remediation or reclamation project. In Serbia, the Ministry gives consent to projects under Article 24 of the Law on Soil Protection.
Applicable values and remediation objectives	Confirm which rules apply to the material being managed, including whether it is assessed as soil or sediment. Document the applicable values and the evidence required to demonstrate that the remediation objective has been met. Agree how reductions in mobility or exposure will be evaluated alongside any applicable concentration-based requirements.
Biomass status and acceptance	Clarify the legal status of each harvested fraction and the requirements for its storage, transport and processing. Obtain written acceptance criteria from the receiving facility. Where waste rules apply, verify the classification and any permits required for the proposed route.
Biochar use and process residues	Confirm the conditions for the intended use of biochar in soil or water treatment and identify a route for residues or spent sorbent. Use the relevant European Biochar Certificate criteria as a quality benchmark alongside applicable legal requirements.
Capacity to operate and monitor the site	Confirm who will plant, harvest, sample and review results over successive seasons. Check access for machinery, laboratory capacity and funding for monitoring. Budget for a fallback route if the receiving facility rejects a batch or the planned outlet becomes unavailable.

Before making the final decision, update the cost estimate to reflect any additional approvals, monitoring, transport or treatment. Carry unresolved conditions into the decision record and assign each one an owner and a deadline.

1. Republic of Serbia. (2015). *Law on Soil Protection*. Official Gazette of the Republic of Serbia, No. 112/2015, Articles 22–26. Tekst propisa. Paragraf
2. Republic of Serbia. (2019). *Rulebook on the Content of Soil Remediation and Reclamation Projects*. Official Gazette of the Republic of Serbia, No. 35/2019. PDF Ministarstva. ekologija.gov.rs
3. Republic of Serbia. (2018, amended 2019). *Regulation on Limit Values for Polluting, Harmful and Hazardous Substances in Soil*. Official Gazette of the Republic of Serbia, Nos. 30/2018 and 64/2019, Articles 3–5 and Annex 1. Tekst propisa. paragraf.rs
4. Republic of Serbia. (2012). *Regulation on Limit Values for Pollutants in Surface Waters, Groundwater and Sediment and Deadlines for Their Attainment*. Official Gazette of the Republic of Serbia, No. 50/2012. PDF Ministarstva. ekologija.gov.rs
5. Republic of Serbia. (2025). *Law on Waste Management*. Official Gazette of the Republic of Serbia, No. 109/2025. Tekst propisa. www.ekologija.gov.rs
6. European Biochar Certificate. (n.d.). *EBC and WBC Guidelines and Documents*, including the EBC certification guidelines and the positive list of permissible biomass feedstocks. Accessed 9 November 2026. EBC guidelines.

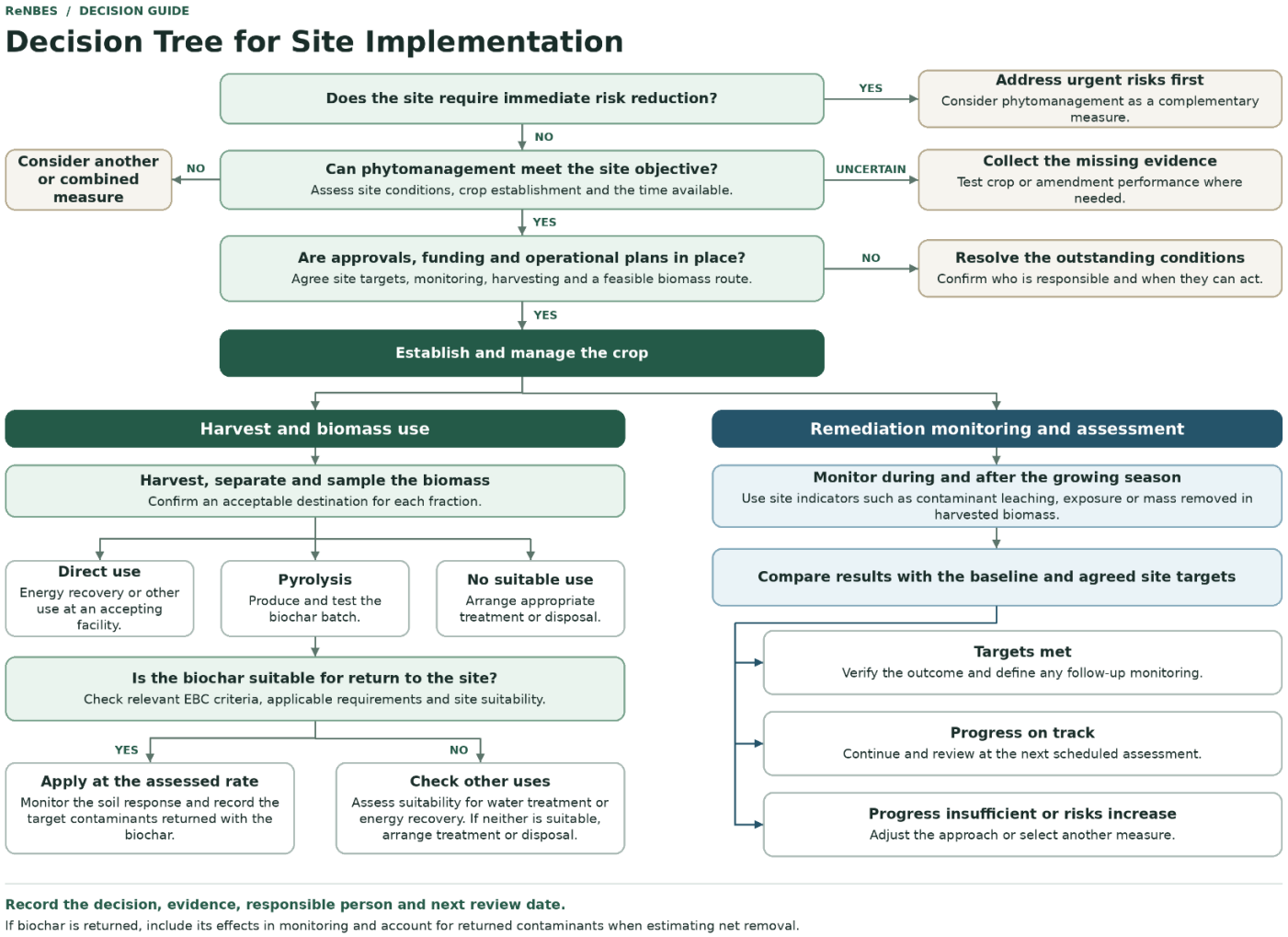
DECISION RECORD

Record the Decision and Next Steps

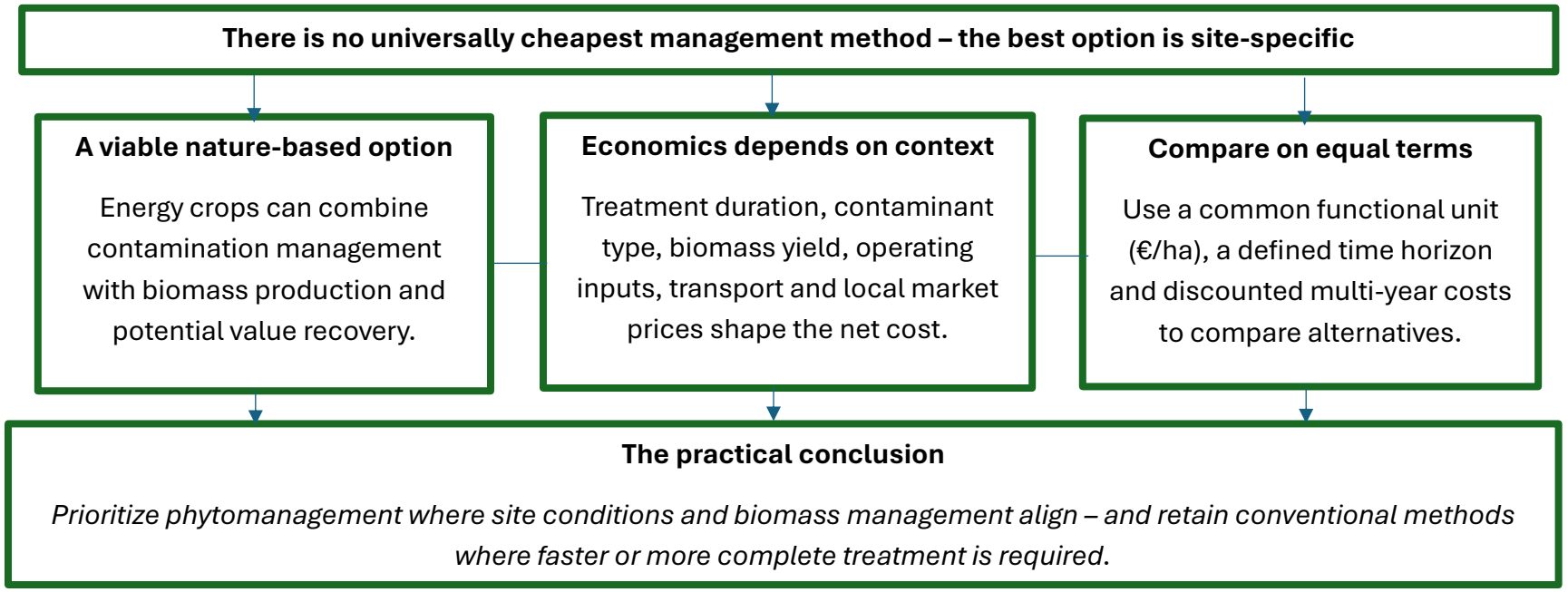
Complete this record at the end of the detailed assessment or pilot review. Attach the evidence used and assign responsibility for each outstanding action.

Record	Complete for the site
Site and intended use	Site or plot _____ Review date _____ Current and planned use _____
Objective and evidence	Priority contaminant and exposure route _____ Required outcome and indicators _____
Biomass and biochar	Harvest destination and acceptance status _____ Biochar route and evidence still needed _____
Costs and responsibilities	Budget scenario and funding source _____ Site lead, operator and authority contact _____
Decision and reason	☐ Collect evidence ☐ Start pilot ☐ Scale up ☐ Adapt or combine measures Reason _____
Next action and review	Action and responsible person _____ Deadline _____ Review date _____

Decision Tree for Phytomanagement



When does energy-crop phytomanagement make economic sense?



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