

Engineering Project Management Methods for Comparing Design Alternatives

By

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Methods for Comparing Design Alternatives

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Introduction

During design, project professionals often need to be able to compare alternatives and select a logical solution. A significant problem or challenge may arise with multiple solutions to be compared. Examples scenarios include:

- Design alternatives such as layouts
- Material choices
- Equipment and technology selection
- Vendor and subconsultant selection
- Change evaluation
- Project rescue options for unexpected issues
- Risk response planning
- Sequencing options

Key benefits to a formal alternatives comparison process include:

- Alignment with project objectives
- Stakeholder input and concurrence
- Transparency in decision-making
- Logical decision-making
- Risk management satisfied
- Encourages innovation
- Enhanced flexibility and adaptability
- Fairness and objectiveness

It is important to have an understanding of the common approaches to comparing alternatives. Some approaches are very high-level to make a quick decision. Other approaches require detailed calculations and significant mathematics.

The following are common approaches to comparing alternatives, in order from simple to complex:

- Advantages Table
- Qualitative Comparison
- Quantitative Comparison
- Multi-Criteria Scoring

This course covers each of these methods, then goes into detail on economic and sustainability comparisons.

Advantages Table

The simplest approach to comparing alternatives is with an Advantages Table or Advantages List. Each alternative is listed with perceived advantages and disadvantages. See Table 1 for comparing roof types for a new building design project.

Table 1: Example Advantages Table

Alt. No.	Description	Advantages	Disadvantages
1	Asphalt Shingle Roof	Fast installation Low cost Color selection	Short life span
2	Clay Tile Roof	Aesthetically pleasing Long life span Storm resistant	Expensive
3	Metal Roof	Long life span Storm resistant Color selection	Expensive

With this approach, there is a lot of flexibility in choosing the criteria to include in the advantages and disadvantages columns. The project objectives and product requirements should be reviewed to help decide on the important criteria for the project.

Often very extreme or very important differences are listed in both the advantages and disadvantages columns (like cost and life span) while less extreme or important differences are only in one column (like color, aesthetics, and storm resistance). This explains why in Table 1, Alternative 1 has an advantage of “fast installation”, but Alternatives 2 and 3 do not have “slow installation” as a disadvantage.

The person responsible for the alternatives comparison is trusted to make judgment decisions as to what criteria to include and when to list advantages/disadvantages in one or both columns. One should be humble enough to seek input from other technical experts to fully understand the impact of each alternative. Often a project manager or client manager will review to see the table through the eyes of the client or customers.

Overall, the advantages table approach is fast and simple but has a lot of subjectivity and may not result in choosing the best alternative.

Qualitative Comparison

An improved approach is a qualitative comparison table. An example for comparing roof types is shown in Table 2. This approach lists several criteria (also called indicators), with a comparison of the alternatives for each criterion. In this case, six criteria are presented: Installation Time, Construction Cost, Color Selection, Aesthetics, Life Span, and Storm Resistance. And the qualitative terms “Best, Average, Worst” are used to compare each alternative for each criterion. Alternately, terms such as “Good, Fair, and Poor” may be used.

Table 2: Example Qualitative Comparison

Alt. No.	Description	Installation Time	Constr. Cost	Colors Available	Aesthetics	Life Span	Storm Resist-ance
1	Asphalt Shingle Roof	**Best**	**Best**	Average	Worst	Worst	Worst
2	Clay Tile Roof	Worst	Worst	Worst	**Best**	**Best**	Average
3	Metal Roof	Average	Average	**Best**	Average	Average	**Best**

Note how Table 2 provides significantly more information than the previous advantages table. It also has less subjectivity since alternatives must be compared for each criterion. Often, this type of comparison table is sufficient to allow selection of an alternative.

Project Selection - Qualitative

Qualitative comparisons are also common for making project selection and prioritization. See Table 3 for an example project comparison table.

Table 3: Qualitative Project Comparison for Project Selection

Proj. No.	Project Name	Constr. Cost	Payback Period	Return on Investment	Risks & Safety	Permit Req's
1	Packaging Upgrade	**Best**	Average	Average	Average	**Best**
2	Storage Facility	Average	Worst	Worst	**Best**	Worst
3	Add Prod. Line C	Worst	**Best**	**Best**	Worst	Average

Looking at Table 3, each potential project is "best" in at least one category. Often at the business stage, the payback period and return on investment criteria hold the most weight, so Project 3 is the most likely to be chosen to proceed. However, it is possible that Project 2 is to replace an existing storage facility that is unsafe, with a history of employee injuries, which would escalate the importance of the project. A notes column can be added for critical information for making a project selection decision.

Quantitative Comparison

The previously discussed alternatives table and qualitative comparison table are commonly used for design decisions with relatively simple and low-cost systems, or for early decisions to be confirmed later during detailed design. A quantitative approach is more common for complex, critical, high-risk, and high-cost systems. A quantitative comparison takes more effort but provides more information to make a more informed choice of alternatives.

A quantitative comparison includes numerical values for comparison, which allows seeing the magnitude of the differences. For example, dollar values are to be listed for the estimated construction cost of each alternative. See Table 4 for an example of a quantitative comparison table. The best values for each criterion are in bold, to help indicate the best alternative.

Table 4: Example Quantitative Comparison

Alt. No.	Description	Installation Time (days)	Constr. Cost (USD)	Colors Available (number)	Aesthetics (1 to 10 scale)	Life Span (years)	Storm Resist-ance (mph)
1	Asphalt Shingle Roof	**3 days**	**$10,000**	20	4	15	110
2	Clay Tile Roof	7 days	$60,000	10	**10**	**50**	125
3	Metal Roof	5 days	$40,000	**100**	6	40	**150**

These types of tables are common for engineering reports with alternatives comparisons. Having numerical values and seeing them in a single table is very helpful.

Project Selection – Quantitative

See Table 5 for an example project comparison table using a quantitative approach. For the last two columns, the scale of 1 to 10 is with 1 being the best and 10 being the worst. Typically, for each such criteria, the worst alternative is set to 10 and the others are set to a comparative number. A score of 5 would indicate half (50%) the amount as the worst alternative.

Table 5: Quantitative Project Comparison for Project Selection

Proj. No.	Project Name	Constr. Cost	Payback Period	Return on Investment	Risks & Safety (1 to 10)	Permit Req's (1 to 10)
1	Packaging Upgrade	**$5M**	10 yrs	50%	6	**2**
2	Storage Facility	$8M	20 yrs	25%	**3**	10
3	Add Prod. Line C	$20M	**5 yrs**	**100%**	10	6

Risk Scoring

Risk scoring involves quantifying the risk profile of an alternative or an existing system or component. For example, in a sewer network, each pipe section is give a risk score and ranked to help select which pipes require replacement. A common approach to risk scoring is to sum the severity of failure and likelihood of failure values (each on the same scale), per this formula:

Risk Score = IF * Severity Score + Likelihood Score
where IF = Importance factor (often 1.5 to 2.5)

Risk ranking is covered in more detailed in a separate risk management course.

Multi-Criteria Scoring

The multi-criteria scoring approach, also called multi-criteria decision analysis (MCDA), uses numerical values for each criterion, similar to a quantitative approach, but also uses those values to calculate a total score for each alternative. The scoring approach minimizes subjectivity and provides transparency in showing how the best alternative is chosen.

See Table 6 for an example of a multi-criteria scoring table with the same six criteria as Table 4 (columns and rows are inverted). In this case, the Metal Roof gets the best score.

Table 6: Example Multi-criteria Scoring Table

Criteria	Weight Factor	Asphalt Shingle		Clay Tile Roof		Metal Roof	
		Normal. Index	Weighted Index	Normal. Index	Weighted Index	Normal. Index	Weighted Index
Installation Time	10	1.0	10	0.4	4	0.6	6
Constr. Cost	30	1.0	30	0.2	6	0.3	9
Colors Available	10	0.2	2	0.1	1	1.0	10
Aesthetics	10	0.4	4	1.0	10	0.6	6
Life Span	20	0.3	6	1.0	20	0.8	16
Storm Resist.	20	0.7	14	0.8	16	1.0	20
Aggregated Index		-	66	-	57		**67**
Final Score[1]		-	0.99	-	0.85		**1.0**

Notes:
1. Higher is better, normalized to 1.0

The final score is the normalized aggregated index, with the best score being 1 in this case. The metal roof alternative has the best score and is the winner of this comparison. Note that for a sustainability comparison, the calculations are typically done with the lowest score being the best and the highest score of 1.0 being the worst.

The scoring technique must take into account that some criteria (also called indicators) are more important than others. In Table 6, construction cost is three times as important as installation time, so it is given three times the “weight” when calculating the final score. Often a small change in the weight factors can result in a different alternative having the best score.

The next section provides detailed instructions on how to perform a scoring comparison.

Steps for Multi-Criteria Scoring

The following figure shows the recommended steps to score and compare alternatives.

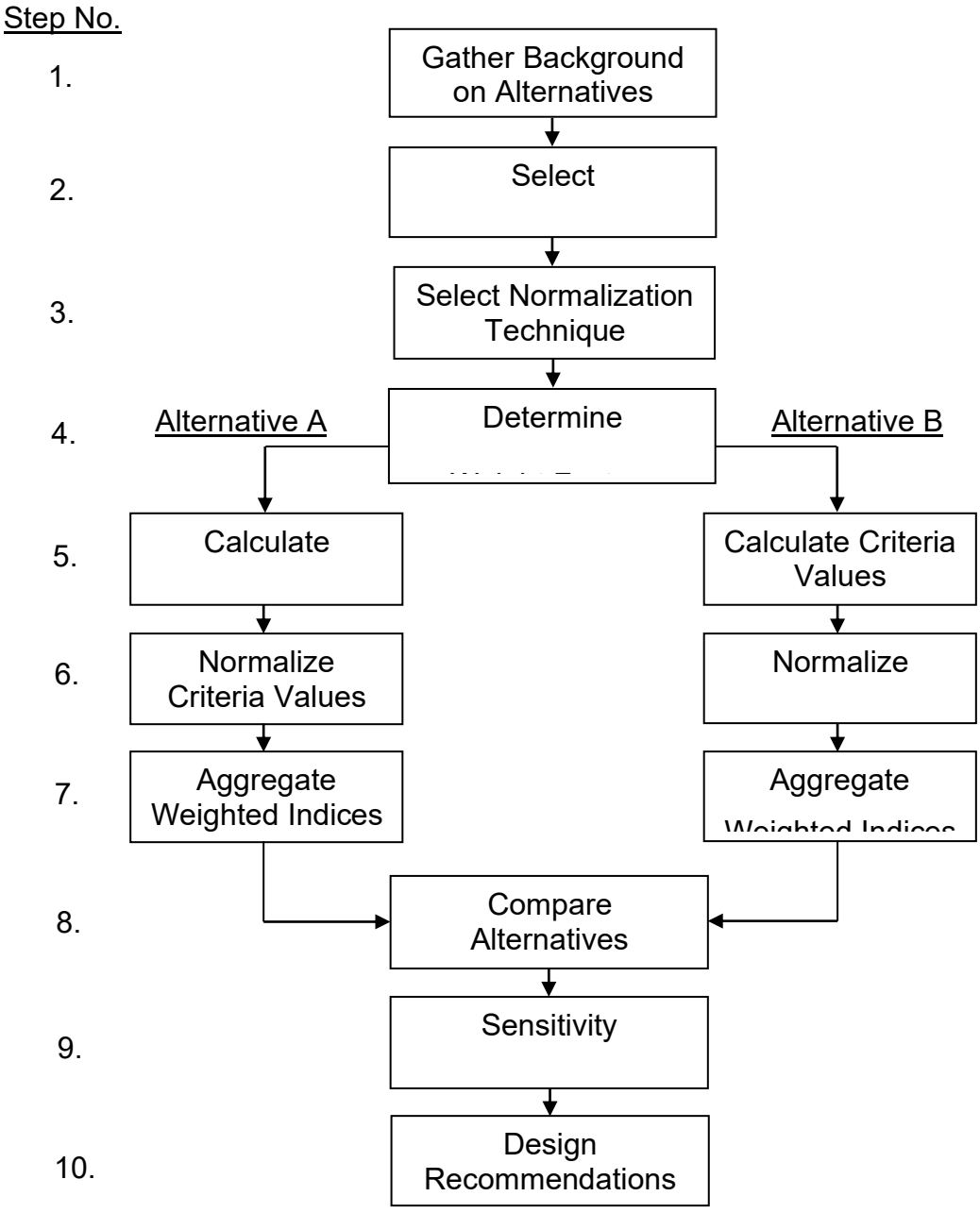


Figure 1: Framework for multi-criteria scoring of alternatives. Additional alternatives can be considered in Steps 5, 6, and 7.
Source: Author

Each step in the multi-criteria scoring framework is described below.

Step 1: Gather Background on Alternatives

The first step is to gather background information on each alternative being considered. Define each alternative and identify key differences and risks.

Step 2: Select Criteria

A good next step is to select the criteria (indicators) that will be used for the comparison. Consider metrics in the business case justification (payback period, safety improvements, regulatory requirements, etc.) and project objectives (level of treatment, capacity, meet customer needs, etc.). Often it is beneficial to create unique criteria to address project specifics. For sustainability comparisons, criteria should be selected in the ecological, economic, and societal categories, as covered later in this course.

Step 3: Select Normalization Technique

Select how criteria values will be normalized. Normalization factors are multiplied by the criteria values to produce numbers with a maximum value of 1 to simplify the aggregation of values and allow a direct comparison of alternatives. There are three common techniques for determining the normalization factors: internal normalization, external normalization, and existing normalization.

- Internal normalization involves calculating the criteria values for each alternative and selecting the greatest or least criteria value as the normalization factor.
- External normalization uses a reference value that is common for the industry or representative of nearby facilities to account for local conditions.
- Existing normalization uses the criteria values of any existing processes as the normalization factors for the alternatives.

The example in Table 6 uses internal normalization with higher values being “better” than lower values.

Step 4: Determine Weight Factors

Determine the criteria weight factors, which typically vary for each project. Consideration may be given to reference standards and organization standards. However, it is common to develop project specific weight factors with input from the project sponsor and other key stakeholders. In the absence of such input, one approach is to initially give equal weight for each of the criteria and then review and adjust after obtaining input from all stakeholders.

To reduce subjective bias, consider calculating weight factors with the Analytic Hierarchy Process (AHP) as listed in the References section. In AHP, direct comparisons are made for each pair of criteria, which breaks down the task of

creating weight factors into less subjective inputs. Criteria comparison inputs can be obtained from those with a vested interest in the project, such as engineers, owners, operators, local authorities, and community members.

Step 5: Calculate Criteria Values

Calculate the criteria values for each alternative. Ensure criteria values have the same units for each alternative. Often a higher value is considered better. However, for sustainability comparisons, the larger the criteria value, the greater the negative ecological, economic, or societal impact. Thus, smaller criteria values indicate greater sustainability and a smaller "footprint".

Step 6: Normalize Criteria Values

Divide each criteria value by the criteria normalization factor (the highest value for each criterion) to obtain a set of normalized indices. The normalization factor can also be an existing conditions value or an industry standard value.

Step 7: Aggregate Weighted Indices

Multiply each normalized index by the weight factor and sum these weighted indices to obtain an overall aggregated index for each alternative. These can be normalized by dividing each aggregated index by the largest aggregated index value. The normalized aggregated indices represent the "final scores" for each alternative. These final scores have a scale of 0 to 1. Depending on the choices made in Step 3, a value of 1 may be the best or worst score.

Step 8: Compare Alternatives

Compare the results for each alternative. Highlight the best alternative and calculate the percent difference from the next best alternative. A radar plot of the normalized indices for each alternative provides a visualization of the results before applying weights. Results can be presented to the project champion and project sponsor.

Step 9: Sensitivity Analysis

A sensitivity analysis reveals if small changes in the calculations can result in a different alternative being chosen as the winner. Start by determining the impact of any assumptions and uncertainties on the criteria values and potential changes in the weight factors of 10% or more. Scores should be recalculated for each extreme in the range of criteria values and weights.

Compare the new results to the original results and assign a plus or minus variance range to each final score. If the ranges overlap for two or more of the best alternatives, there should be decreased confidence in declaring a winning alternative.

Step 10: Design Recommendations

Use the results to consider opportunities to improve the design of each of the alternatives. For any design changes, recalculate the criteria values and aggregated indices.

Proper documentation should be maintained at each of these steps, so a quality review can be performed. There are many opportunities to make mistakes with math or logic, and a brief review by a coworker can confirm the results and any conclusions.

Lifecycle Cost

Lifecycle cost (LCC) is a popular criterion for comparing alternatives and project justification in the business case. LCC is also used for sustainability analysis and long-term budgeting. LCC refers to the total cost of ownership over a set time period(or the life of an asset), including construction, maintenance, energy usage, operation labor, chemical use, waste disposal, and demolition.

Many capital improvement projects add systems and processes that require significant ongoing operations and maintenance costs which need to be taken into account. The LCC is often considered when preparing a business case and making a project go/no-go decision.

Often a time period of 20 years is used for a lifecycle analysis. All alternatives should use the same time period.

Present Worth LCC

The lifecycle cost can be calculated using the present worth approach. The formula is as follows:

$$Lifecycle\ Cost = Capital\ Cost + Annual\ O\&M * PWF - Salvage\ Value$$

where: $Annual\ O\&M = annual\ operations\ and\ maintenance\ costs$

$$PWF = Present\ Worth\ Factor = \frac{(1+i)^T - 1}{i*(1+i)^T}$$

$i = interest\ rate\ (or\ discount\ rate)$

$T = number\ of\ years$

Simplified LCC

Given the high variability in cost estimates at the business case, study or preliminary design stage, it is common to ignore PWF and salvage value, and use this simplified LCC formula:

$$Lifecycle\ Cost = Capital\ Cost + Annual\ O\&M * Years$$

The simplified LCC approach is also common if inflation is high or similar to interest rates, or if discount rates are low, since the present worth factor (PWF) will be similar to the “number of years”.

Consider O&M during Design

Smart decisions should be made early in the design process to minimize operations and maintenance (O&M) costs over the lifecycle of installation. As a project progresses, opportunities for reducing lifecycle cost diminish as the design becomes solidified. It is helpful to consider operations impacts early in the design process, such as during studies, basis of design reports, and preliminary design. This allows for a better Annual O&M cost estimate.

Example Problem 1

Given the following, calculate the 20-year lifecycle cost with the simplified approach:

- Capital Cost = $8M
- Annual O&M = $100,000

Solution:

Using the simplified LCC formula:

$$Lifecycle\ Cost = Capital\ Cost + Annual\ O\&M * Years$$

$$\boldsymbol{Lifecycle\ Cost} = \$8{,}000{,}000 + \$100{,}000 * 20 = \mathbf{\$10{,}000{,}000}$$

Return on Investment

Return on Investment (ROI) is a common criterion for project selection and justification in the business case stage of a project. ROI is the anticipated profit as a percent of project cost. ROI applies to projects that have profit or cost savings as a goal. Some projects don't have profit or savings and thus won't have an ROI, such as projects to improve safety or meet regulatory requirements.

A common ROI formula for a project is as follows:

$$ROI = \left(\frac{Revenue - Project\ Cost}{Project\ Cost}\right) * 100 = \left(\frac{Net\ Profit}{Project\ Cost}\right) * 100$$

The above formula requires an assumption on the time period (number of years) for the revenue and doesn't include operations and maintenance costs. Therefore, the following ROI formula is more comprehensive and applicable to capital improvement projects.

$$ROI = \left(\frac{Annual\ Revenue * Years - Lifecycle\ Cost}{Lifecycle\ Cost}\right) * 100$$

Here, lifecycle cost includes capital (construction) costs plus ongoing operations costs over a time period, usually 20 years. See the previous section for more details on calculating lifecycle costs.

Some projects provide cost savings instead of revenue/profit. For example, a new digester and biogas generator would produce electricity and heat which results in energy bill savings but not revenue. In such cases, the ROI formula is as follows:

$$ROI = \left(\frac{Annual\ Savings * Years - Lifecycle\ Cost}{Lifecycle\ Cost}\right) * 100$$

Anticipated ROI is often calculated as part of the business case to justify the project. Often a high and low range are calculated since the estimated cost and revenue are very rough at that stage. ROI should be updated whenever there are budget changes in the project or external influences that impact the anticipated revenue.

Example Problem 2

A solar power upgrade project is estimated to save $200,000 a year in electricity costs. The project is expected to cost $700,000 to construct and $50,000 a year in operations and maintenance costs (not including the electricity cost savings). Ignoring interest, what is the ROI for a 20-year period?

Solution:

Use the following ROI formula:

$$ROI = \left(\frac{Annual\ Savings * Years - Lifecycle\ Cost}{Lifecycle\ Cost}\right) * 100$$

$$Annual\ Savings = \$200{,}000/yr$$

$$Years = 20\ yr$$

$$Lifecycle\ Cost = Capital\ Cost + Annual\ O\&M * Years$$

$$Lifecycle\ Cost = \$700{,}000 + \$50{,}000 * 20 = \$1{,}700{,}000$$

$$\boldsymbol{ROI} = \left(\frac{\frac{\$200{,}000}{yr} * 20\ yr - \$1{,}700{,}000}{\$1{,}700{,}000}\right) * 100 = \left(\frac{\$2{,}300{,}000}{\$1{,}700{,}000}\right) * 100 = \mathbf{135\%}$$

Payback Period

Another criterion used to justify a new project is the "payback period". The payback period is the time it takes for a project to recover its capital cost and start to generate a net profit or net savings. Similar to ROI, some projects are not intended to create profit and savings and will not have a payback period.

The following is a common formula:

$$Payback\ Period = \frac{Project\ Cost}{Annual\ Revenue - Annual\ Costs}$$

Or, if a project results in savings instead of profit:

$$Payback\ Period = \frac{Project\ Cost}{Annual\ Savings - Annual\ Costs}$$

Example Problem 3

What is the payback period for a project with the following:

- Project Cost = $3,000,000
- Annual O&M Costs = $60,000
- Annual Savings = $300,000

Solution:

The following formula is used:

$$\boldsymbol{Payback\ Period} = \frac{Project\ Cost}{Annual\ Savings - Annual\ O\&M\ Costs}$$

$$= \frac{\$3{,}000{,}000}{\$300{,}000 - \$60{,}000} = \mathbf{12.5\ years}$$

Multi-Criteria Scoring Example

Jenny is a project manager (PM) working on a project for the design of a new storage facility. For the building material, Jenny asked the project sponsor if there is a preference for materials of construction. The project sponsor said that two options would be acceptable: a metal building (with insulated panels) or tilt up concrete panels. He requested to compare and choose based on capital cost, 20-year lifecycle cost, energy loss (heating and cooling), flexibility for future building changes, and lead time. Capital cost is twice as important as all the rest of the factors.





Figure 2: Top) Metal building with insulated panels
Bottom) Installation of concrete tilt-up panels for a new building.

Sources: commons.wikimedia.org/wiki/File:Pre_engineered_steel_buildings_PEB_Steel_Buildings_Co.,_Ltdb2.._131.JPG, MarPEB, CC-BY-SA 3.0; commons.wikimedia.org/wiki/File:JAX_Training_facility_project_construction_(8390183836).jpg, NAVFAC, CC-BY-2.0

Jenny holds a planning meeting with the design team and conveys the sponsor's request. In the meeting it is agreed to perform a multi-scoring comparison with the 10 steps presented in Figure 1. The team assignments are as follows:

- Estimator: Calculate the capital cost and 20-year lifecycle cost
- Structural engineer: Determine the energy loss through the walls and quantify the flexibility for future building changes
- Purchasing specialist: Contact suppliers for pricing and lead times
- PM Jenny: Create the score table and input values provided by team members

Step 1: Background on Alternatives

The storage building needs an area of 10,000 square feet with a minimum side wall height of 30 feet. The purchasing specialist discusses the application with two metal building suppliers and a tilt-up building contractor. They request information on the occupancy type and wind loading. The purchasing agent forwards the questions to the structural engineer who provides the requested details.

The structural engineer looks up typical insulation values for each of the wall types. For the metal building option, he assumes 2" thick panels will be used. For the tilt-up option, he selects insulated sandwich panels which increase the R-value (measure of thermal resistance where higher is better) versus traditional tilt-up concrete walls.

The structural engineer also researches how metal panel walls and tilt-up concrete walls can be modified in the future for the addition of doors, windows, awnings, or to connect to a building expansion.

Step 2: Select Indicators

Jenny lists the agreed criteria provided by the project sponsor:

- Capital cost
- Lifecycle cost
- Energy loss
- Flexibility
- Lead time

Step 3: Select Normalization Technique

Jenny chose the internal normalization technique since this is a direct comparison between the two building types, without an existing roof or industry standard for comparison. Jenny decides that lower values will be better, with a final scoring range of 0 to 100.

Step 4: Determine Weight Factors

Jenny computes the weight factors based on the project sponsor's direction for capital cost to be double the others. The factors need to add to 1 (100%), so she divides 1 by 3 for capital cost, and 1 by 6 for the other four factors.

Table 7: Weight Factors for Building Type Comparison		
Criteria	Calculation	Weight Factor
Capital cost	1 / 3	0.333
Lifecycle cost	1 / 6	0.167
Energy loss	1 / 6	0.167
Flexibility	1 / 6	0.167
Lead time	1 / 6	0.167
Total (round to 100%)		1.0

Step 5: Calculate Criteria Values

For this comparison, the larger the criteria value, the worse the score. For criteria that are scaled from 0 to 100, the number 0 represents the best value possible. Jenny receives information from her team and compiles it in the following table.

Table 8: Criteria Values from the Team		
Criteria	Metal Building	Tilt-up Building
Capital cost	$1.0M	$1.6M
Lifecycle cost	$1.5M	$1.8M
Energy loss	R-16	R-12
Flexibility	High Flexible	Moderate Flexibility
Lead time	20 weeks	6 weeks

Step 6: Normalize Criteria Values

Jenny calculates the normalized indices by setting the largest value as 100 and dividing the smaller value by the larger value and multiplying by 100. Jenny input the normalized index values in Table 9 and makes the better values bold. It can be seen that the metal building has the advantage in four of the five categories, including the category with the most weight.

Table 9: Normalized indices for each Building Type

Criteria	Metal Building		Tilt-up Building	
	Value	Norm. Index	Value	Norm. Index
Capital cost	$1.0M	**63**	$1.6M	100
Lifecycle cost	$1.5M	**83**	$1.8M	100
Energy loss	R-16	**67**	R-12	100
Flexibility	High Flexible	**50**	Moderate Flexibility	100
Lead time	20 weeks	100	6 weeks	**30**

Step 7: Aggregate Weighted Indices

Jenny multiplied each normalized index by the associated weight factor to obtain the weighted index. She then sums the weighted indices to obtain an overall aggregated index for each alternative, as shown in Table 10. Jenny normalized the aggregated indices to get a final score for each alternative.

Table 10: Final Scoring for each Building Type					
Criteria	Weight Factor	Metal Building		Tilt-up Building	
		Norm. Index	Weight Index	Norm. Index	Weight Index
Capital cost	0.333	63	**21.0**	100	33.3
Lifecycle cost	0.167	83	**13.9**	100	16.7
Energy loss	0.167	67	**11.2**	100	16.7
Flexibility	0.167	50	**8.4**	100	16.7
Lead time	0.167	100	16.7	30	**5.0**
Aggregated Index		-	**71.2**	-	88.4
Final Score		-	**80.5**	-	100
Notes: 1) Lower is better, Normalized to 100					

Step 8: Compare Alternatives

Jenny observes that the metal building has a lower score, and thus it is the "winner" of the comparison. The metal building scored approximately 20% lower than the tilt-up building, which is a significant difference. The metal building scored better in capital cost, which is the most important factor. The tilt-up building only score better in lead time but scored significantly better in that criteria due to the short time needed to mobilize and begin pouring concrete and tilting up wall panels. If schedule becomes more important, it may be worth updating the comparison.

Step 9: Sensitivity Analysis

With a 20% difference in the scores of the two alternatives, Jenny has a high level of confidence in declaring the metal building is better for this project.

Step 10: Design Recommendations

In the process of evaluating these alternatives, the team identified the following design features for consideration:

- Use high energy star rated products
- Add solar panels on the roof for green energy
- Add anchor points on the roof for safety
- Color scheme, frames, and decorated shutters to match nearby facility
- Add a downspout to a rain barrel for stormwater management

- Add stainless steel plating along the interior wall around the washdown area
- Use exterior floor mounted A/C units (instead of roof mounted)
- Add double doors to allow equipment passage

Jenny had a coworker review the table, and then she presented her findings to the project sponsor and project champion. They agreed to proceed with the metal building. Several of the design recommendations were integrated into the design.

Comparing Sustainability

It is increasingly common to consider sustainability when selection a project or when designing a new product, process, or facility. Sustainability strives to meet the needs of the present without compromising the ability to meet future needs. It is based on the principle that it is our responsibility to protect the people and environment that may be affected by the item being designed.

Sustainability can be achieved when the human health and natural environment can be maintained or improved over time, without exceeding the ecological capabilities that support them. In terms of design, this involves consideration for the long term impact on the community and environment.

Sustainability is commonly evaluated by considering the following three categories:

1. Economic: Maximize value, wealth, and profits in the economically viable dimension.
2. Environmental: Provide cleaner products with less raw material consumption and waste generation in the environmentally compatible dimension.
3. Social: Have more socially benign products, services, and impact in the socially responsible dimension.

These three categories are referred to as the “triple bottom line” or the three P’s: profit, planet, and people. The categories are depicted in Figure 3 with the overlap of the three being defined as sustainable.

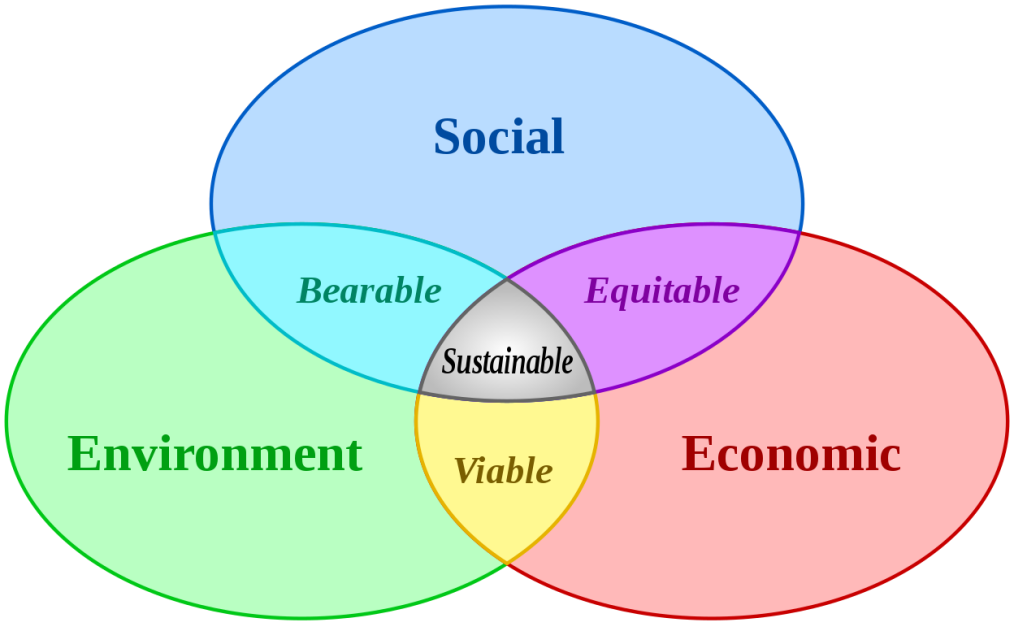


Figure 3: Triple Bottom Line for Sustainable Development

Within each category, there are a number of criteria (indicators) that can be used to numerically assess the sustainability of an improvement. This allows for quantification of the triple bottom line and declaring if something is more or less sustainable than some other option, including the “do nothing” option.

It is now relatively common to compare the sustainability of alternatives during the preliminary design stage to facilitate decision making. This provides long-term value to the project, society, and the environment.

Comparing sustainability of two alternatives can be applied using the same approaches to comparing alternatives, namely:

- Advantages Table
- Qualitative Comparison
- Quantitative Comparison
- Multi-Criteria Scoring

The main difference is that indicators are all related to the areas of sustainability.

At a glance, it would appear difficult to compare the sustainability of alternatives because the social and environmental categories seem vague and subjective. However, commonly accepted methodologies have been developed to quantify and calculate sustainability with reduced subjectivity.

Sustainability assessment software is available as a tool. However, such software tends to be either too broad or too focused on specific industries, providing limited

benefit to most improvement projects which have a unique mix of design elements. The following is some software for awareness.

Eco-Efficiency Analysis

Eco-Efficiency Analysis™ is a tool to assess the environmental impact versus the cost-effectiveness. It was established by BASF Corporation in 1996. The Eco-Efficiency Analysis methodology has been validated by NSF International. It also follows ISO standards for environmental life cycle assessments and life cycle costs. The environmental impact and economic impact of alternatives can be plotted to help select a balanced path forward.

Envision

Envision™ Sustainable Infrastructure is an approach developed by the Institute for Sustainable Infrastructure (ISI). Envision provides a consistent approach for evaluating and rating infrastructure projects in terms of community, environment, and economic impact. The approach encourages ongoing assessment of the sustainability criteria over the course of the project's life cycle. There is an option for third-party project verification. Envision includes 64 sustainability and resilience criteria, called 'credits'. The credits are grouped into five categories:

- Quality of Life,
- Leadership,
- Resource Allocation,
- Natural World, and
- Climate & Resilience

Organization Worksheets

Some organizations such as municipalities have adopted multi-criteria decision making worksheets that are tailored for local values for sustainability. For example, the Milwaukee Metropolitan Sewerage District (MMSD) has developed a standard sustainability scoring worksheet evaluating alternatives during the preliminary design stage. And the Green Bay Metropolitan Sewerage District (GBMSD) has presented a similar worksheet with sustainability criteria and weights that can be utilized for comparing design alternatives. Such worksheets make it relatively easy for an engineer to fill in quantities for each alternative and be given scoring results with clear rankings for sustainability.

However, in the absence of software or an adopted worksheet, the design engineer will need to perform a project-specific sustainability comparison. This is typically done with a multi-criteria scoring approach, which engineers have been using for decades to compare alternatives in a variety of contexts.

The next section reviews potential criteria for a sustainability comparison.

Sustainability Criteria

The selection of criteria, also called indicators, is an important part of a sustainability assessment and/or comparison of the sustainability of alternatives. Typically, an engineer will select a unique set of criteria based on the project specifics. Ideally, the criteria will reflect the potential sustainability impacts of all the alternatives.

The following are potential criteria to consider, organized according to the triple bottom line categories of sustainability:

1. Economic
    a. Capital Cost
    b. Construction Cost
    c. Operating Cost
    d. Lifecycle Cost
    e. Litigation Risk
    f. Life Span
    g. Return on Investment
    h. Payback Period

2. Environmental
    a. Potable Water Consumption
    b. Stormwater Management
    c. Solid Waste Produced
    d. Wastewater Produced
    e. Energy Consumption (nonrenewable)
    f. Recycling / Beneficial Reuse
    g. Greenhouse Gas Emissions (non-biogenic)
    h. Air Pollution
    i. Water Pollution
    j. Impact to Natural Areas (forests, wetlands, coastlines, etc.)
    k. Impact to Protected Species

3. Social
    a. Employee Productivity
    b. Safety
    c. Risk score
    d. Chemical Use
    e. Regulatory Acceptance
    f. Partnership Potential
    g. Stakeholder Support
    h. Aesthetics
    i. Land Use
    j. Job Creation

To keep the analysis manageable, criteria are chosen to reflect the *significant* sustainability impacts, and minor or insignificant impacts are neglected. The chosen criteria should be independent of each other to the greatest extent possible so that an impact is not counted more than once and so criteria and weights can be easily adjusted during the evaluation process.

Societal criteria can be difficult to quantify. For example, aesthetics can be a very important factor in the design and selection of an alternative, yet it is challenging to quantify aesthetics because each person has a different perspective and opinion on what is tasteful and beautiful.

Sustainability Scoring Example

Ivy is acting as both the project manager and environmental engineer for a project to select a sustainable solution to reduce sewer odors. There have been several complaints of a bad smell in one of the neighborhood parks. The odors were tracked to a nearby sewer structure. An odor removal system is desired to address the issue.

Ivy identified two alternatives for odor control: 1) a biofilter bed system and 2) an activated carbon system. Ivy decided to use the multi-criteria approach to compare the two alternative odor control systems and to discover ways to improve the sustainability of each system.

Step 1 - Background on Alternatives

Ivy started by reviewing the design of each odor control system. She developed a preliminary size and layout of each system, as summarized below.

Activated Carbon System

The activated carbon system functions by blowing odorous air through activated carbon media which adsorbs the hydrogen sulfide, H_2S, and other odorous pollutants. An exhaust pipe discharges treated air directly to the atmosphere. A schematic of the system is shown in Figure 4.

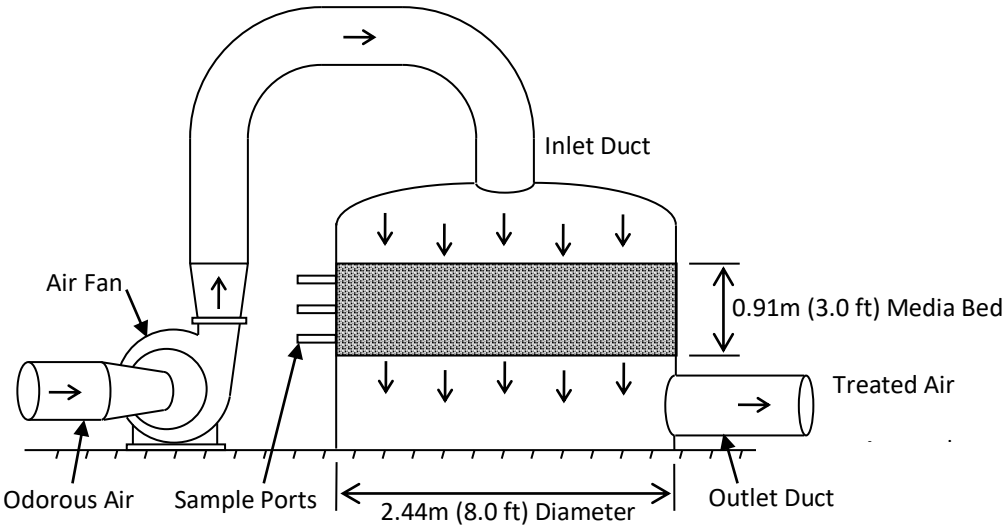


Figure 4: Schematic diagram of the activated carbon system.

Source: Author

Components of the activated carbon system are as follows:

- Air fan with a 5.6 kW (7.5 HP) motor and control panel
- Cylindrical fiberglass enclosure
- Bed of pelletized activated carbon contained by the enclosure
- Inlet and outlet air ducts

The carbon media is virgin, pelleted, caustic impregnated bituminous coal. It can be regenerated a limited number of times using an in-situ caustic solution treatment. Often operators will choose media replacement over regeneration to avoid hazardous chemical handling. The lifespan of the activated carbon is calculated as the adsorption capacity divided by the H_2S load. In this case, the capacity is 597,940 g H_2S, and the load 61.4 g H_2S/h, resulting in a lifespan of 406 days, or 1.11 years.

Biofilter Bed System

The biofilter bed system also uses a blower to draw air from the sewer structure. The odorous air is forced through a buried biofilter bed which removes the odor compounds and emits treated air to the atmosphere. A schematic of the system is shown in Figure 5.

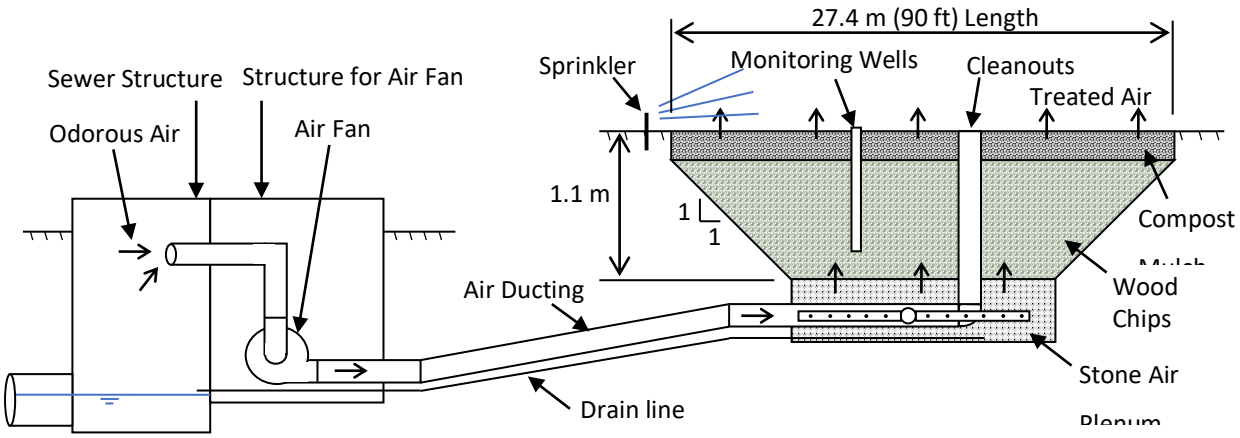


Figure 5: Schematic diagram of the biofilter bed system.

Source: Author

Components of the biofilter bed system are as follows:

- Air fan with a 14.9 kW (20 HP) motor and control panel
- Inlet and outlet air ducts
- A network of perforated pipes at the bottom of the bed in a stone plenum
- Biofilter bed composed of wood chips
- Moisture is maintained by an automatic spray irrigation system
- Monitoring wells
- Surface layer of compost that can sustain a flower bed

Odor removal is accomplished by bacteria living on the surface of the wood chips. The bacteria convert H_2S to sulfuric acid. To keep the bacteria active in removing odors, the media must remain moist, and so daily irrigation is required. Ordinary wood chips obtained from local residents are acceptable.

Step 2 – Selection of Indicators

To help select the criteria, Ivy reviewed a reference paper on sustainability metrics and an example sustainability assessment. She made a list of potential criteria and considered which were most relevant to the activated carbon and biofilter bed systems. Ivy chose the following six criteria for the comparison:

1. Economic
    a. Lifecycle Cost

2. Environmental
    a. Energy Use
    b. Water Use
    c. Solid Waste
    d. Greenhouse gas (GHG) emissions

3. Social
    a. Aesthetics

Step 3 - Selection of Normalization Technique

Ivy chose the internal normalization technique since the study is a direct comparison between the biofilter bed and activated carbon systems.

Step 4 - Determination of Weight Factors

Ivy decided to gain the input of three stakeholders in determining the weights for the six criteria. She also decided to use the Analytic Hierarchy Process (AHP). Ivy conducted a survey to give each of the stakeholders. The survey listed each combination of two criteria and asked the respondent to choose the more important criteria from each pair, along with the level of importance, called the intensity. The survey feedback was averaged, and results are shown in Table 11.

Table 11: Direct comparisons of Indicators for AHP Calculation			
Criteria A	Criteria B	More Important Criteria	Intensity (0 to 9)
Energy Use	Aesthetics	Energy Use	6
Energy Use	GHG Emissions	Energy Use	4
Energy Use	Lifecycle Cost	Equal	2
GHG Emissions	Aesthetics	Equal	3
GHG Emissions	Lifecycle Cost	Lifecycle Cost	6
Lifecycle Cost	Aesthetics	Lifecycle Cost	6
Solid Waste	Aesthetics	Solid Waste	3
Solid Waste	Energy Use	Energy Use	4
Solid Waste	GHG Emissions	Solid Waste	2
Solid Waste	Lifecycle Cost	Lifecycle Cost	4
Solid Waste	Water Use	Solid Waste	2
Water Use	Aesthetics	Water Use	2
Water Use	Energy Use	Energy Use	3
Water Use	GHG Emissions	Equal	1
Water Use	Lifecycle Cost	Lifecycle Cost	4

Ivy used the intensity results in Table 11 to calculate weight factors using the AHP approach. She entered the intensities in a matrix with each criterion as a row and column and performed algebra to obtained averaged weight factors. Table 12 shows the completed matrix with the average values on the right being the weight factors with a scale of 0 to 1. These weight factors are multiplied by 100 to be shown as a percent.

Table 12: AHP Matrix with Resulting Weight Factors							
	Aesthetics	Cost	GHG	Energy	Water	Waste	**Weight**
Aesthetics	0.046	0.065	0.025	0.043	0.042	0.034	**0.042**
Cost	0.292	0.410	0.425	0.450	0.366	0.375	**0.387**
GHG	0.138	0.072	0.075	0.074	0.085	0.061	**0.084**
Energy	0.292	0.246	0.275	0.270	0.254	0.375	**0.285**
Water	0.092	0.095	0.075	0.090	0.085	0.051	**0.081**
Waste	0.138	0.112	0.125	0.074	0.169	0.102	**0.120**

Step 5 - Calculation of Criteria Values

Ivy calculated the criteria values for each of the two systems based on a 20-year lifecycle. Her work is summarized below.

Energy Use

The activated carbon system has an air fan motor that will consume approximately 4500 W continuously, resulting in an energy use per unit airflow is 1.02 W/(m^3/h). The biofilter bed system has an air fan motor that will consume an average of 13,400 W continuously, resulting in an energy use per unit airflow is 2.63 W/(m^3/h).

Water Use

The activated carbon unit only uses water for cleaning operations, requiring an estimated 5 L/d (1.32 gpd), which totals 1825 L/yr, or 0.415 (L/yr)/(m^3/h). The biofilter bed spray system runs twice a day at one hour each time, from spring until fall. The rotor heads release approximately 1800 L/d (475 gpd) for 200 days per year, for an average 360,000 L/yr, or 70.6 (L/yr)/(m^3/h).

Solid Waste

The only waste produced by the activated carbon system is the annual landfill disposal of spent media, which results in a waste quantity of 2460 kg/yr (5420 lb/yr), or 0.559 (kg/yr)/(m^3/h). For the biofilter bed, media needs to be replaced approximately every five years, with spent media disposed of at a landfill. The weight of disposed wood chips and compost is 12,835 kg/yr (28,300 lb/yr). The weight of the replacement wood chips is subtracted since they are from recycled yard waste that is saved from disposal. Therefore, the biofilter bed solid waste is 4066 kg/yr (8963 lb/yr), or 0.797 (kg/yr)/(m^3/h).

Lifecycle Cost

Lifecycle cost is calculated as the present worth of capital costs and annual operation costs, using a present worth factor. A timeframe of 20 years is assumed, with an interest rate of 5%, resulting in a present worth factor of 12.46. For the activated carbon system, capital costs are $116,300 and operation costs are $19,100 per year, resulting in a present worth cost of $354,300 or $80.52/($m^3$/h). For the biofilter bed system, capital costs are $65,200 and operation costs are $18,700, resulting in a present worth cost of $298,200 or $58.47/($m^3$/h).

GHG Emissions

The activated carbon system does not have a significant impact on direct GHG emissions in the air stream during operation; however, there are indirect GHG emissions resulting from the initial carbonization and activation of the media, and the system electrical energy use. The initial carbonization and activation of the carbon media has been reported to emit 560 g of carbon dioxide and 54 g of methane per kg of media, resulting in the emission of 1377 kg CO_2/yr and 133 kg CH_4/yr. The Global

Warming Potential, GWP, of methane is 25 CO_2 equivalents (CO_2e) based on a 100-year time horizon. So, the methane emission is 3325 kg CO_2e/yr, for a total GHG emission of 4702 kg CO_2e/yr. Also, there are GHG emissions due to electrical energy consumption, which is calculated to be 27,950 kg CO_2e/yr using the United States regional emissions factor of 0.7094 kg CO_2e/kWH. Therefore, the activated carbon system GHG emissions are 7.42 (kg CO_2e/yr)/(m^3/h).

Biofilter beds have been found to remove methane gas due to the natural presence of methanotrophic bacteria. The methane loading rate is estimated at 10.94 g/(m^2h), which corresponds to a methane removal rate of 35%. The result is the removal of 16,250,000 kg CO_2e/yr. GHG emissions due to electrical energy consumption are 83,280 kg CO_2e/yr using the same regional emissions factor. Therefore, the biofilter bed GHG emissions are a net reduction of 3170 (kg CO_2e/yr)/(m^3/h).

Aesthetics

The aesthetic impact is scored using a ratio of negative to positive attributes. The activated carbon system has four negative attributes (requires enclosure/building, exposed ductwork, visually unnatural, limited configurations available) and one positive attribute (small footprint), resulting in a score of 4. The biofilter bed has two negative attributes (large footprint, air fan requires enclosure/building) and two positive attributes (bed can be below ground, visually natural) giving it a score of 1.

Step 6 - Normalization of Criteria Values

Ivy normalized the results as shown in Table 13. For GHG emissions, the biofilter bed system has a negative criteria value, but a normalized index of 0 is assigned since that is the minimum allowed value for aggregation. The activated carbon system has lower values in energy use, water use, and solid waste. The biofilter bed has lower values in lifecycle cost, GHG emissions, and aesthetics. Ivy double checked that lower values indicate an increase in sustainability for all criteria.

Table 13: Summary of Indicators and Normalized Indices				
Criteria	Units	System	Criteria Value	Normalized Index
Energy Use	$\frac{W}{m^3/h}$	Carbon	1.02	0.388
		Biofilter	2.63	1.000
Water Use	$\frac{L/yr}{m^3/h}$	Carbon	0.415	0.005
		Biofilter	70.60	1.000
Solid Waste	$\frac{kg/yr}{m^3/h}$	Carbon	0.559	0.701
		Biofilter	0.797	1.000
Lifecycle Cost	$\frac{\$}{m^3/h}$	Carbon	80.52	1.000
		Biofilter	58.47	0.726
GHG Emissions	$\frac{kg\ CO_2e/yr}{m^3/h}$	Carbon	7.42	1.000
		Biofilter	-3170	0.000
Aesthetics	$\frac{Negative}{Positive}$	Carbon	4	1.000
		Biofilter	1	0.250

Step 7 – Aggregation of Weighted Indices

Ivy calculated the weighted indices for each criterion by multiplying the normalized index by the weight factor, as shown in Table 14. The indices were summed to provide an aggregated index and final score for each alternative. The lower value is considered more sustainable.

Table 14: Final Scoring for Odor Control Sustainability Comparison					
Criteria	Weight Factor	Activated Carbon		Biofilter Bed	
		Normalized Index	Weighted Index	Normalized Index	Weighted Index
Energy Use	28.5	0.388	11.058	1.000	28.500
Water Use	8.1	0.005	0.041	1.000	8.100
Solid Waste	12.0	0.701	8.412	1.000	12.000
Lifecycle Cost	38.7	1.000	38.700	0.726	28.096
GHG Emissions	8.4	1.000	8.400	0.000	0.000
Aesthetics	4.2	1.000	4.200	0.250	1.050
Aggregated Index		-	**70.811**	-	77.746
Final Score (Normalized to 1)		-	**0.911**	-	1.000

Step 8 – Comparison of Alternatives

Ivy reviewed the results which indicate that the activated carbon system is overall slightly more sustainable with a score that is 8.9% lower than the biofilter bed system. Ivy observed that each system has three criteria in which they are considered more sustainable, so the weight factors have a significant influence on the overall outcome.

The lifecycle cost criterion has the greatest weight, and the biofilter bed has a lifecycle cost that is 15.8% lower than the activated carbon system due to relatively low capital costs. The energy use criterion has the next greatest weight, and the activated carbon system uses 61.2% less energy, so it gains a significant advantage. Ivy concluded that the lower energy use is the single biggest reason the activated carbon system won the comparison.

Ivy made the radar diagram displayed in Figure 6 to view the normalized criteria values graphically. This plot assumes equal criteria weights. The area encompassed by each system represents the unsustainable impact of the system, with a smaller area indicating increased sustainability. The biofilter bed has a slightly smaller area and without the weight factors it would be considered 2.9% more sustainable.

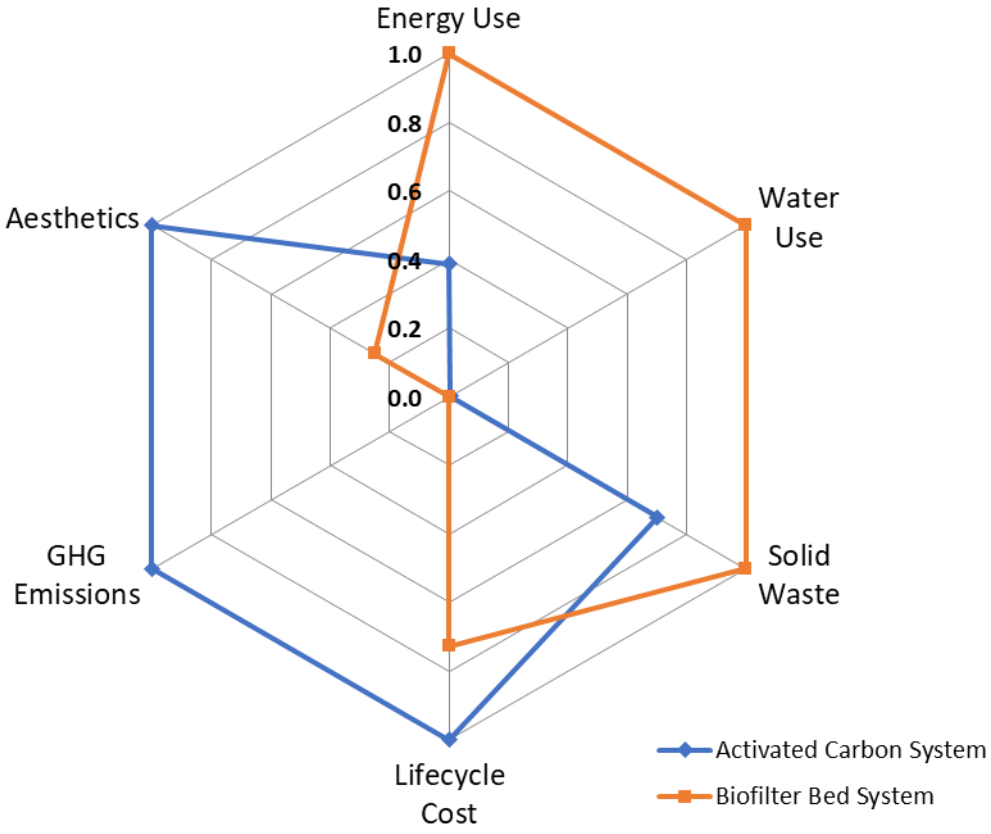


Figure 6: Radar diagram of normalized indices for each alternative. A smaller area corresponds with a smaller footprint and being more sustainable.
Source: Author

Step 9 – Sensitivity Analysis

Ivy reviewed her criteria value calculations and realized that the energy use, water use, and GHG emission values for the biofilter bed included assumptions and could vary greatly due to operating conditions. She recalculated the scores for the range of assumptions and concluded that energy use is the only criterion that would have a significant impact on the final score. For example, if the biofilter bed energy use were 25% lower, the final score of the two systems would be very similar, however the activated carbon system would still be the winner.

Ivy noted that the values for aesthetics for both systems will vary by location; however, with such a small weight value, aesthetics does not have a great effect on the comparison results. There appears to be no calculation assumption that would change the final result that the activated carbon system is slightly more sustainable.

Ivy wondered if selecting different criteria would impact the results. She found two reference comparisons that used different criteria and weights. She recalculated the scores with the different criteria and weights. The first reference did not include

aesthetics and results in the activated carbon system being 14.9% more sustainable. The second reference did not include water use and gave much less weight to energy use, and results in the biofilter bed system being 14.5% more sustainable. These results confirm that importance given to energy use decides which of the two systems is more sustainable.

Step 10 – Design Recommendations

Ivy identified several design modifications that would increase sustainability. For the activated carbon system, both lifecycle costs and solid waste can be decreased significantly by using a recently developed surface-modified non-impregnated activated carbon which can be regenerated with water instead of caustic soda. This media has an added catalytic functionality which oxidizes H_2S and converts it to water-soluble sulfur compounds. The regeneration wastewater appears acceptable to release into the sewer system, and regeneration can be done 10 times before media replacement is required.

For the biofilter bed system, significant energy reduction can be achieved by using a variable frequency drive (VFD). Without the VFD, the operating point on the fan curve moves across a large range so that most of the time the air fan is running at low efficiency. With a VFD, the air fan speed can be slowed during low pressure to provide the same airflow rate with the benefits of power savings of nearly 50%, reduced sound, and increased air fan longevity. The VFD can be programmed to adjust the speed according to pressure gauge readings. The energy cost savings over the 20-year lifecycle would fully offset the initial cost of the VFD.

Ivy presented her findings to the project sponsor and project champion, and it was decided to proceed with an activated carbon system with water regeneration media.

Course Summary

Common approaches for comparing alternatives are summarized below.

- Advantages Table:
  - Each alternative is listed with perceived advantages and disadvantages
  - Very subjective and high-level

- Qualitative Comparison:
  - Table with a best-worst type of comparison for each criterion
  - Common for making project selection decisions

- Quantitative Comparison:
  - Table with numerical values for each criterion
  - Allows seeing the magnitude of the differences
  - Common for design team to calculate values

- Multi-Criteria Scoring:
  - Multi-criteria decision analysis (MCDA)
  - Includes weight factors for criteria, to account for priorities
  - Total scores are summed and normalized for each alternative
  - Allows for comparing numerical scores and declaring a winner
  - A ten step guide is provided for performing multi-criteria scoring
  - Sensitivity analysis checks if small changes in weight factors or design options may change the outcome of the winner

Key economic criteria are as follows:

- Lifecycle cost: Total cost of ownership over a set time period
- Return on investment: Anticipated profit as a percent of project cost
- Payback period: Time period for a project to recover its capital cost and start to generate a net profit or net savings

Sustainability comparisons utilize criteria in the areas of the triple bottom line: economic, environmental, and social.

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Methods for Comparing Design alternatives - Quiz

Updated: 12/26/2025

1) **Which of the following is NOT a common approach to comparing alternatives?**
    a. Advantages Table
    b. Qualitative Comparison
    c. Single-Criteria Scoring
    d. Multi-Criteria Scoring

2) **A table that lists criteria with terms "Good, Fair, and Poor" is an example of which approach?**
    a. Advantages Table
    b. Multi-Criteria Scoring Table
    c. Quantitative Comparison
    d. Qualitative Comparison

3) **How is Multi-Criteria Scoring different from other comparison approaches?**
    a. More than one criterion is used
    b. Total numerical scores are given
    c. Results are shown in a table
    d. Competition based

4) **Which of the following are common normalization techniques?**
    a. First, last, same
    b. Internal, external, and reference
    c. Internal, external, and standard
    d. Internal, external, and existing

5) **At what step should criteria be selected?**
    a. After normalizing the indicator values
    b. After calculating the indicator values
    c. After gaining background information on the alternatives
    d. First thing

6) **For a sustainability comparison, criteria should be chosen from which categories?**
    a. Economic, Environmental, Social
    b. Standards, References, Project
    c. Past, Present, Future
    d. Best, Equal, Worst

7) Which of the following criteria is in the Social category?

a. Operating Cost
b. Stormwater Management
c. Aesthetics
d. Lifecycle cost

8) Which of the following criteria is in the Environmental category?

a. Litigation Risk
b. Safety
c. Payback period
d. Solid waste

9) Which of the following criteria is in the Economic category?

a. Lifecylce Cost
b. Energy Consumption
c. Partnership Potential
d. Waste produced

10) Which of the following is NOT true for selecting criteria?

a. Can be based on stakeholder inputs
b. Consider business case metrics and project objectives
c. Criteria should be independent of each other
d. Economic criteria are the most difficult to quantify

11) Analytic Hierarchy Process is a technique for determining weight factors

a. True
b. False

12) What is the goal of a sensitivity analysis?

a. Check how sensitive the stakeholders are to design changes
b. Have another engineer review the calculations
c. Check if small changes in weight factors can result in a different winner
d. Consider emotional impact

13) Sustainability strives to do which of the following?

a. Minimize cost above all else
b. Meet the needs of the present without compromising the ability to meet future needs
c. Maintain things the same
d. Last forever

14) Comparing the results is the last step in multi-criteria scoring.

a. True
b. False

15) An advantages table is subjective and high-level.

a. True
b. False

16) Which comparison allows seeing the magnitude of the differences?

a. Advantages Table
b. Qualitative Comparison
c. High-level comparison
d. Quantitative Comparison

17) What do weight factors account for?

a. Priorities
b. Sustainability
c. Loads
d. Mass

18) What is the 10-year ROI if annual savings are $200k and lifecycle cost is $1.5M?

a. 3%
b. 33%
c. 100%
d. 133%

19) Which is a simplified formula for lifecycle cost?

a. LCC = Construction Cost + Operations Cost
b. LCC = Capital Cost + Commissioning Cost + Warranty Cost
c. LCC = Construction Cost + Commissioning Cost + Warranty Cost
d. LCC = Capital Cost + Annual O&M x Years

20) What is the payback period if annual savings are $60k, annual costs are $10k, and project cost is $200k?

a. 4 years
b. 5 years
c. 10 years
d. 14 years