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Standard Guide for Investment Analysis in Environmentally Sustainable Manufacturing[1]

This standard is issued under the fixed designation E3200; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers techniques for evaluating manufacturing investments from the perspective of environmentally sustainable manufacturing by pairing economic methods of investment analysis with environmental aspect of manufacturing, including manufacturing processes.

1.2 The economic techniques discussed include net present value, internal rate of return, payback period, and hurdle rate. These four techniques are deterministic, meaning that they deal with known values that are certain. Probabilistic considerations play no role in determining how these four techniques are deployed. The guide will also move beyond standard deterministic techniques to look at probabilistic methods like the concept of sensitivity analyses with a focus on Monte Carlo analyses.

1.3 The techniques can be used by manufacturers, regardless of size or complexity, to make environmentally sustainable decisions, including but not limited to whether to embark on an investment, discontinue a manufacturing line, invest or re-invest in a new project or factory. To outline all possible decision types would constitute a guide in itself.

1.4 This guide does not assume specific knowledge of financial techniques on the part of the user, besides some knowledge of discounting. The interested reader is encouraged to follow up and consult outside readings to cover financial techniques beyond the scope of this guide.

1.5 This guide uses U.S. dollars, percent change in environmental aspects of manufacturing, and unit change in environmental aspects of manufacturing as its primary units.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E833 Terminology of Building Economics

E1057 Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems

E2114 Terminology for Sustainability Relative to the Performance of Buildings

E2921 Practice for Minimum Criteria for Comparing Whole Building Life Cycle Assessments for Use with Building Codes, Standards, and Rating Systems

E2986 Guide for Evaluation of Environmental Aspects of Sustainability of Manufacturing Processes

E2987/E2987M Terminology for Sustainable Manufacturing

E3096 Guide for Definition, Selection, and Organization of Key Performance Indicators for Environmental Aspects of Manufacturing Processes

2.2 *ISO Standards:*[3]

ISO 14025 Environmental labels and declarations — Type III environmental declarations — Principles and procedures

ISO 14040 Environmental management — Life cycle assessment — Principles and framework

ISO 14044 Environmental management — Life cycle assessment — Requirements and guidelines

ISO 14049 Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis

[1] This guide is under the jurisdiction of ASTM Committee E60 on Sustainability and is the direct responsibility of Subcommittee E60.13 on Sustainable Manufacturing.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

ISO 14067 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification
ISO 21930 Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services

3. Terminology

3.1 *Definitions*—For definitions used in this guide, refer to Terminologies E2114, E2987/E2987M, and E833.

4. Summary of Guide

4.1 This guide covers techniques for evaluating manufacturing investments from the perspective of environmentally sustainable manufacturing. This guide pairs economic methods of investment analysis with environmental aspects of manufacturing. The method presented includes five steps:

4.1.1 *Step 1*—Conduct economic and environmental assessments;

4.1.2 *Step 2*—Evaluate whether there are tradeoffs between economic and environmental choices;

4.1.3 *Step 3*—Identify tradeoff metric and evaluate tradeoff;

4.1.4 *Step 4*—Perform sensitivity analysis (optional); and

4.1.5 *Step 5*—Rank investment choices.

4.2 There are four types of investment decisions for which four methods of financial economic analysis are applied along with metrics (indicators) for environmental aspects of manufacturing. Different methods apply to different decision types. When combined, financial economic analysis and metrics for environmental aspects of manufacturing result in a combination of outcomes, each associated with an additional procedure.

5. Significance and Use

5.1 This guide provides a method for evaluating investments in terms of their financial merits and environmental merits. This guide can be used to answer whether an investment is both economical and environmentally sustainable or if there is a tradeoff between the environmental aspects of manufacturing and profitability. In the event that there are tradeoffs, this guide provides methods for evaluating those tradeoffs.

5.2 The financial merits for this guide are typically from the individual stakeholder perspective (for example, owners or investors, or both) or from the perspective of a selection of stakeholders. It is up to the users to decide what financial changes are relevant to them. For instance, if there is a financial cost borne by a third party, the users may opt to exclude it from their analysis, as it is not relevant for them. The environmental merits are from a multi-stakeholder perspective (for example, societal level) and should follow established standards for evaluating environmental aspects of manufacturing. That is, environmental aspects of manufacturing should not be excluded simply because they do not affect the user.

6. Procedure

6.1 As seen in Fig. 1, the method presented includes an iterative process incorporated into a five-step procedure. The first step includes an economic (6.3) and environmental (6.4) assessment. The economic assessment evaluates the financial merits of an investment while the environmental assessment evaluates the environmental aspects of manufacturing resulting from the investment. Both assessments evaluate potential

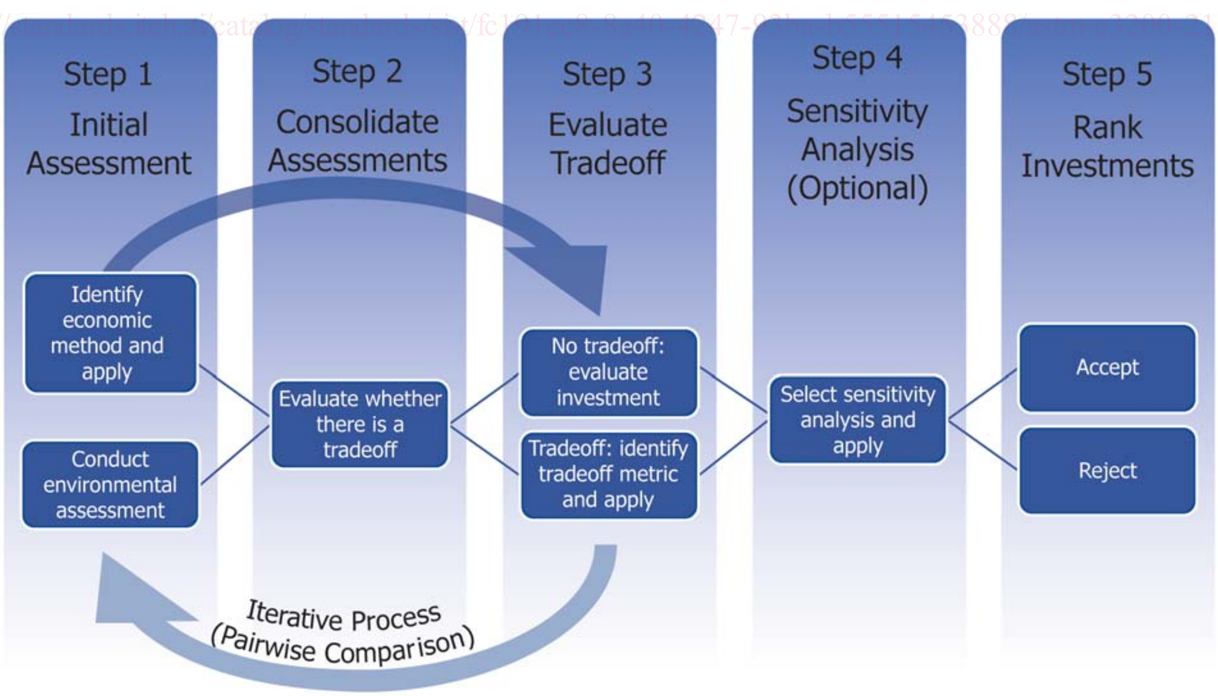


FIG. 1 Five Steps for Environmentally Sustainable Investment Analysis

investments relative to the status quo (that is, base case). Steps 2 (6.5) and 3 (6.6) bring these assessments together for comparison and consider any tradeoffs. The outcome of the economic and environmental assessment results in any one of a number of outcome combinations, each having its own implications. Depending on the outcomes, the first three steps may need to be repeated. Step 4 (6.7) evaluates the impact of uncertainty in the data. There are often variables that are not known with certainty and there is a need to consider the possibility of having different values, resulting in different outcomes. The final step, Step 5 (6.8), is to rank the investments.

6.2 Multiple economic and environmental assessments are being completed and compared. The scope of each economic/environmental assessment is the change that results from a particular investment. For an economic assessment, it is the change in finances that result in the investment. For an environmental assessment, it is the change in the environmental aspects of manufacturing that results from the investment.

6.3 *Step 1.1 - Initial Assessment—Identify Economic Method and Apply:*

6.3.1 The first part of Step 1 (that is, Step 1.1) is an economic analysis. There are four types of economic decisions: accept/reject, design, size, and priority/ranking. An accept/reject decision does not compare investments, but rather determines whether an investment meets a threshold level of performance. A design decision pertains to choices between variations of an investment where only one can be selected. A sizing decision is one that involves different magnitudes within an investment, where only one magnitude can be selected. A ranking decision includes prioritizing and then selecting one or more investments from a group when a budget is not sufficient to fund all cost-effective investments. Examples for each of the decision types are presented in Table 1.

6.3.2 Four basic approaches for financial economic analysis are discussed in this guide. Different approaches are appropriate for each of the four decision types, as defined in Table 2. Net present value is appropriate for three of the decision types: accept/reject, design, and size. Internal rate of return is appropriate for all four decision types, while hurdle rate and payback period are only appropriate for accept/reject decisions. Annex A1 details each of the methods for financial economic analysis.

6.4 *Step 1.2 - Initial Assessment—Conduct Environmental Assessment:*

6.4.1 Step 1.2 is to examine the environmental aspects of manufacturing of the proposed investments. This guide is not intended to contradict or circumvent the provisions of ISO 14025, ISO 14040, ISO 14044, ISO 14067, ISO 14049, or ISO 21930 and encourages their use and, if the assessment is of a building, Practice E2921. For the purpose of the method presented here, the user can either use a percent change in environmental aspects of manufacturing or a unit change (for example, tons of carbon dioxide emitted). These environmental impacts could be measured using methods presented in Guide E3096.

6.4.2 Guide E3096 provides a procedure for identifying key performance indicators for the environmental aspects of manufacturing processes. It also provides a procedure for normalizing key indicators, assigning weights, and aligning them with environmental objectives.

6.4.3 One additional standard that can be utilized for evaluating the environmental aspects of manufacturing is Guide E2986. This guide provides guidance to develop procedures for evaluating environmental sustainability performance of processes in manufacturing. This guide addresses a number of issues, including setting boundaries and identifying process- and equipment-related parameters.

6.4.4 The methods presented here in this guide are designed to make comparisons across a single metric (indicator) of environmental aspects of manufacturing measured as either its percent change or the unit change resulting from the investment. For simplicity, the guide relies on percent change. To use unit change, the user can simply replace the measure of percent change with the preferred units. Guide E3096 provides methods of defining and selecting key performance indicators, including a process for aggregating multiple indicators into a single metric.

6.4.5 For this guide, an investment is considered environmentally favorable if the percent change or unit change is less than or equal to zero (that is, does not increase the environmental impact). It is considered to be environmentally unfavorable if the percent change or unit change is greater than zero (that is, an increase in environmental impact). In the case where Step 1 and Step 2 are being repeated (discussed in 6.5.4.3 and 6.5.4.4), the denominator, EI_a', in Eq 1 does not

TABLE 1 Examples of Decision Types

Accept/Reject	• Is an additive manufacturing system cost effective? • Is a new climate control system cost effective? • Is a new robotic system cost effective
Design	• What robotic system is the most cost effective • What HVAC control system is the most cost effective? • Which milling machine is he most cost effective? • Is it more cost effective to use steel or aluminum materials?
Size	• How many machine tools should be replaced? • What size of lathe is most cost effective?
Priority or Ranking	• Is it more cost effective to invest in new machine tools or a new HVAC control system? • We have five proposed investments but can only afford a selection of them. Which investments do we choose?

TABLE 2 Appropriate Application of Financial Economic Methods

	Net Present Value	Internal Rate of Return	Hurdle Rate	Payback Period and Discounted Payback Period
Accept/Reject	X	X	X	X[A]
Design	X	X[B]	...	...
Size	X	X[B]	...	...
Priority or Ranking	X	X	...	...

[A] Note significant limitations

[B] Appropriate when incremental discounted costs and benefits are considered (that is, the difference in costs/benefits between two investments). To decide between more than two options, pairwise comparisons are necessary.

change. Moreover, in the first iteration, EI_a' equals EI_a; however, in subsequent iterations, they will not be equivalent. This is done so that one percentage point of environmental impact always equals the same nominal amount throughout the evaluation. The percent change between two investment options *a* and *b* can then be estimated:

$$PC_e = \frac{(EI_b - EI_a)}{EI_a'} \times 100 \quad (1)$$

where:

PC_e = percent change in environmental impact between option *a* (that is, base case) and potential investment option *b*;

EI_a' = environmental impact of the status quo (that is, initial base case), which does not change throughout the evaluation;

EI_a = environmental impact of investment option *a*; and

EI_b = environmental impact of investment option *b*.

6.5 *Step 2 - Consolidate Assessments—Evaluate Whether There is a Tradeoff:*

6.5.1 As presented in the first four columns of Fig. 2, bringing the environmental assessment together with the economic assessment results in a series of potential outcome combinations, referred to as scenarios, for each investment being assessed. Therefore, one might be comparing investments from multiple scenarios (or the same scenario) within a decision type. In the following sections, each decision type is discussed with references made to the scenarios in Fig. 2, along with a decision tree for each decision type. The scenarios in the decision trees correspond with those in Fig. 2.

6.5.2 *Accept/Reject Decisions*—If a decision is an accept/reject decision for both the environmental and financial assessment (that is, scenarios 1.1 through 1.4), then the investment is only acceptable if both assessments are accepted (see scenario 1.1) and, therefore, no scenarios are compared. This process can be traced in the decision tree in Fig. 3.

6.5.3 *Accept/Reject with Priority/Ranking Decision*—If a decision is a combination of accept/reject and ranking/priority (that is, scenarios 2.1 through 3.4), then all but two of the scenarios are rejected, as seen in the decision trees in Figs. 4 and 5. There could be multiple investments categorized as scenario 2.1 or 3.1. If this is the case, then there is a comparison based on either the financial assessment (applicable to scenario 2.1) or the environmental assessment (applicable to scenario 3.1).

6.5.4 *Design, Size, and Ranking/Priority Decisions*—If a decision is a design, size, or ranking/priority decision type (that is, scenarios 4.1 through 4.4), then there are four possible scenarios for each investment being evaluated. A series of guidelines need to be followed for this decision type. Scenarios

Decision Type	Scenario	Environmental Assessment	Economic/Financial Assessment	Action
Accept/Reject	1.1	Accept	Accept	Acceptable Investment
	1.2	Accept	Reject	Reject
	1.3	Reject	Accept	Reject
	1.4	Reject	Reject	Reject
Environ: Accept/Reject - Economic: Ranking/Priority	2.1	Accept	Financially Economical	Select on $
	2.2	Accept	Not Financially Economical	Reject
	2.3	Reject	Financially Economical	Reject
	2.4	Reject	Not Financially Economical	Reject
Environ: Ranking/Priority - Economic: Accept/Reject	3.1	Environmentally Favorable	Accept	Select on Env.
	3.2	Not Environmentally Favorable	Accept	Reject
	3.3	Environmentally Favorable	Reject	Reject
	3.4	Not Environmentally Favorable	Reject	Reject
Design, Size, Ranking/Priority	4.1	Environmentally Favorable	Financially Economical	Pairwise Comparison
	4.2	Not Environmentally Favorable	Not Financially Economical	Reject
	4.3	Not Environmentally Favorable	Financially Economical	Consider Tradeoff/ Pairwise Comparison
	4.4	Environmentally Favorable	Not Financially Economical	Consider Tradeoff/ Pairwise Comparison

FIG. 2 Consolidating Assessment: Combinations of Outcomes

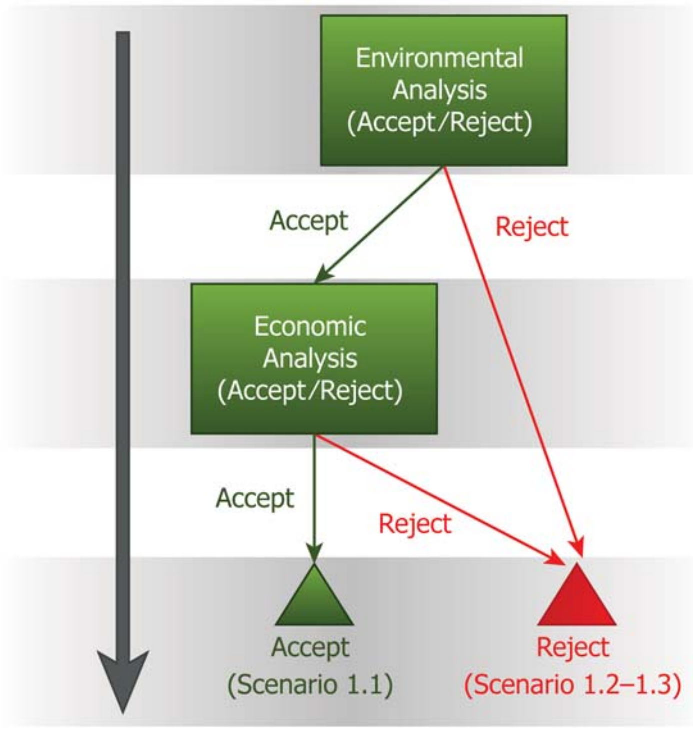


FIG. 3 Decision Tree for Accept/Reject Decisions

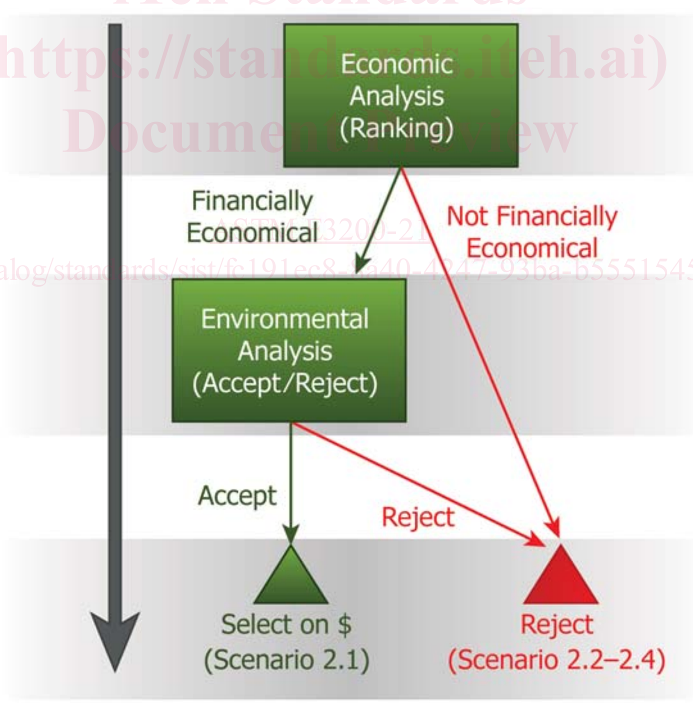


FIG. 4 Decision Tree where Environmental Analysis is Accept/Reject Decision and Economic Analysis is Priority/Ranking Decision

where only one alternative to the status quo is considered (see Fig. 6) are considered separately from those that have two or more alternatives (see Fig. 7).

6.5.4.1 *One Alternative*—As seen in Fig. 6, there are three potential outcomes for those instances where there is only one alternative to the status quo. The first potential outcome is when the alternative is ranked better than the status quo in both environmental terms and economic terms (see scenario 4.1). In this case, the alternative is preferred to the status quo. The second potential outcome is that the alternative is ranked worse in both economic and environmental terms (see scenario 4.2). In this case, the status quo is preferred to the alternative being considered. The last potential outcome has a tradeoff when compared to the status quo (see scenarios 4.3 and 4.4). The

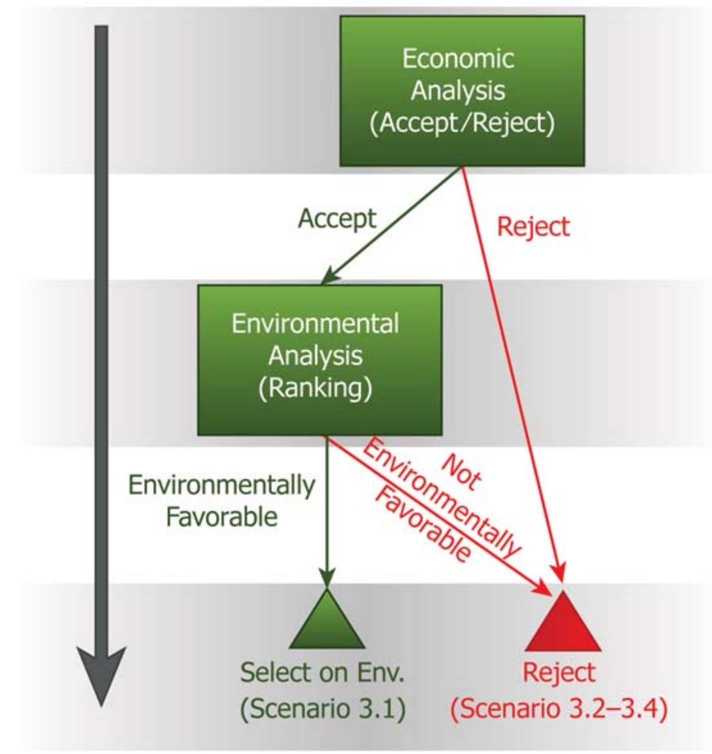


FIG. 5 Decision Tree where Economic Analysis is Accept/Reject Decision and Environmental Analysis is Priority/Ranking Decision

tradeoff involves one of two situations: *(1)* an economical investment that increases environmental impact, or *(2)* an investment that is not economical that decreases environmental impact. In this case, the user must decide whether the investment with the tradeoff is better or worse than the status quo. A selection of tradeoff metrics is discussed in Step 3 shown in 6.6.

6.5.4.2 *Two or More Alternatives*—For instances where there is more than one alternative to the status quo, the user follows the decision tree in Fig. 7. Similar to Fig. 6, if an investment is not economical, and it is not environmentally favorable (scenario 4.2), then that investment is not preferred to the status quo. Investments that are both economically and environmentally favorable must be compared in a pairwise comparison, as discussed in 6.5.4.3. If there is a tradeoff (scenarios 4.3 and 4.4), then the user must determine if the tradeoff is preferred to the status quo. A selection of tradeoff metrics is discussed in Step 3 shown in 6.6. If the tradeoff is preferred, then a pairwise comparison must be made between the other alternatives.

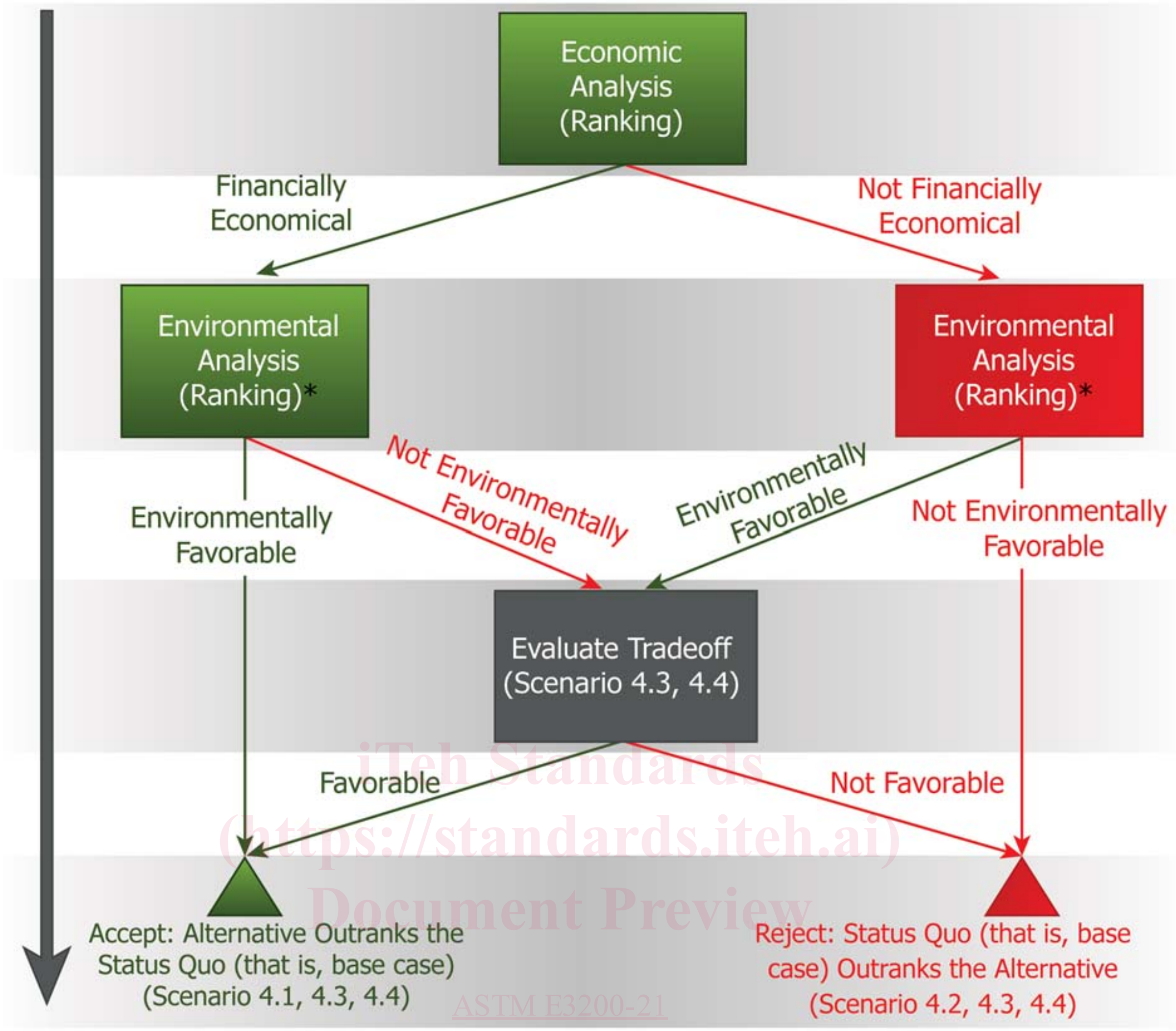
6.5.4.3 *Pairwise Comparison*—In the case where there are multiple alternative investments, it may be necessary to conduct a pairwise comparison where each investment is compared relative to each of the other investments. The result will rank all of the investments. This requires repeating Step 1 and Step 2, but only considering two investments at a time. In each comparison, one investment is selected as the new status quo (that is, a new base case) while the other investment is treated as a potential alternative investment to the new status quo. Each of the comparisons will result in using Fig. 6 to determine if the alternative is preferred to the new status quo. Additional investments then can be compared to determine where they rank relative to the others.

6.5.4.4 Fig. 8 illustrates how investments are compared in a pairwise comparison. In this example, it was determined that Investments A, B, and C were each preferred over the status quo. A second iteration compared Investment A with Investment B, which resulted in determining that A is preferred to B. A second iteration is needed to determine if Investment C is preferred to A or B, or both. Investment C can be compared to Investment A to determine if it is ranked 1^{st}. If Investment C is not preferred to A, then it must be compared to Investment B to determine whether it is ranked 2^{nd} or 3^{rd}. Note that in the case where Step 1 and Step 2 are being repeated, the denominator, EI_a', in Eq 1 from Step 1.2 (6.4) does not change when using a percent change, as previously discussed. Moreover, in the first iteration EI_a' equals EI_a; however, in subsequent iterations they will not be equivalent. This is done so that one percentage point of environmental impact always equals the same nominal amount of environmental impact throughout the evaluation.

6.6 *Step 3 - Evaluate Tradeoff:*

6.6.1 A tradeoff exists when *(1)* a scenario includes an investment that is not environmentally favorable but is financially economical, or *(2)* a scenario includes an investment that is not financially economical, but is environmentally favorable. Each of these has a set of metrics for evaluation.

6.6.2 *Not Environmentally Favorable and Financially Economical*—There are four metrics for considering a tradeoff where the investment is not environmentally favorable: maximum impact, the net present value per percent change in



*These two boxes represent the same environmental analysis and not two separate or different analyses.

FIG. 6 Decision Tree for Design, Size, and Ranking/Priority Decisions, One Alternative

environmental impact (NPVP), environmental hurdle rate, and the net present value elasticity (NPVE). Each of these are discussed in 6.6.4.1 through 6.6.4.6.

6.6.3 *Not Financially Economical but Environmentally Favorable*—There are four metrics for considering a tradeoff where the investment is not financially economical but is environmentally favorable: maximum environmental expenditure, maximum environmental expenditure rate (MEER), NPVP, and the NPVE. Each of these metrics are discussed in 6.6.4.1 through 6.6.4.6.

6.6.4 The following sections discuss the tradeoff metrics, which are applicable to investments that are either *(1)* not environmentally favorable and financially economical, or *(2)* not financially economic but environmentally favorable.

6.6.4.1 *Maximum Impact*—The maximum impact is the largest acceptable increase in environmental impact. It can either be in percent or in units (for example, tons of CO_2). It is compared to the change in impact for the investment being evaluated and is applicable when the change in environmental impact is positive (that is, an increase in the impact). If the impact of the investment is greater than the maximum impact, then the investment is rejected or ranked lower when compared to the status quo. For instance, if an investment increases the environmental impact by 10 %, and the maximum impact for the investor is 5 %, then the investment would be ranked lower than the status quo.

6.6.4.2 *NPVP*—This value is the average increase or decrease in income brought about by each percentage point change (or unit change) in environmental impact. It is calculated as:

$$NPVP = \frac{NPV}{PC_e} \quad (2)$$

where:

NPVP = net present value per percent increase in environmental impact.