City of Tacoma Lifecycle City

The search for a Sustainability-Based decision making tool

West Coast climate Forum Material Management Committee
February 19, 2013

Presentation Outline

- Lifecycle City Resolution
- Results from First LCA analysis of City utility performance
- Quest for LCA Certification
- Search for Sustainable Return on Investment (SROI) Decision-Making Tools

Lifecycle City
Adopted January 25, 2011

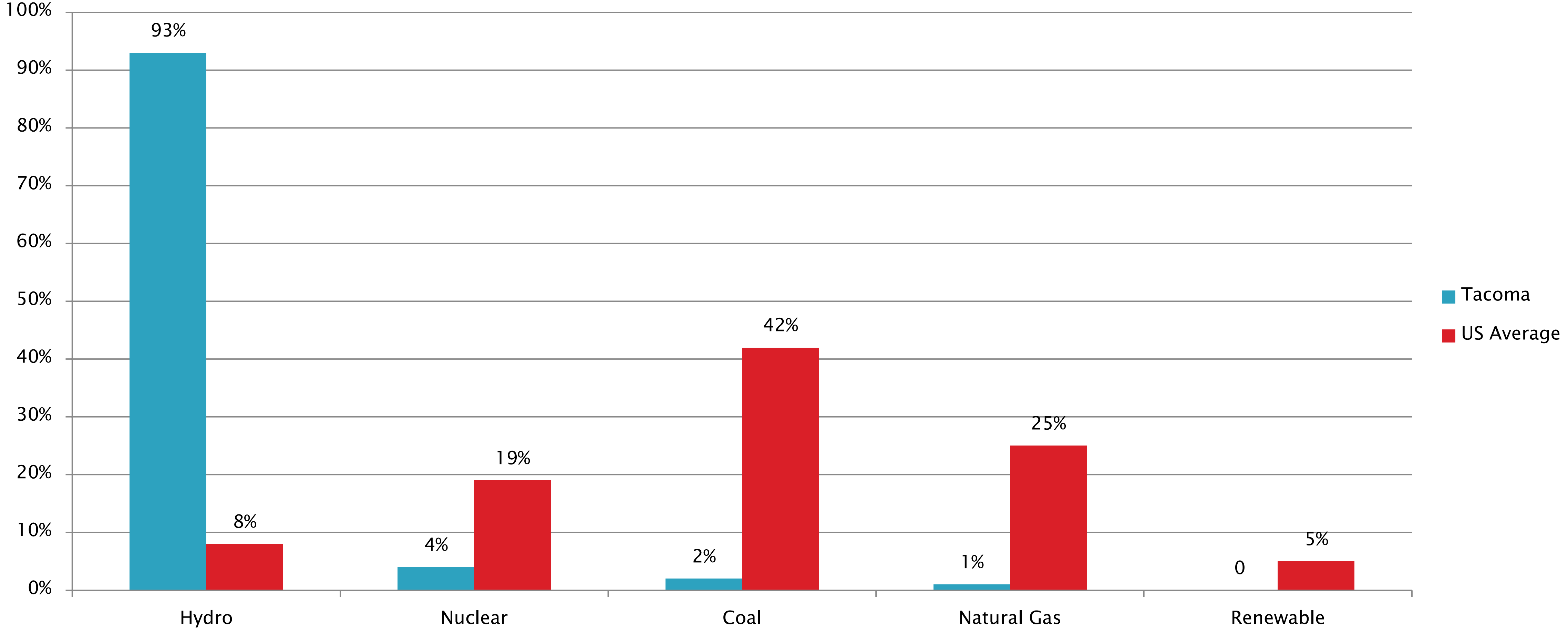
- City commits to:
  - Integrate Life Cycle Assessments and Life Cycle principles in its relevant purchases and operations
  - Maintain and provide ongoing life cycle inventory data for its utility operations. Data shall include:
    - Energy, water, fuel and other relevant products usage
    - Air and water pollution
    - Waste emitted
  - Educate staff in lifecycle thinking and principles
  - Work with higher education and community partners to increase citywide capacity for lifecycle thinking

Carbon Footprint Results from First Assessment

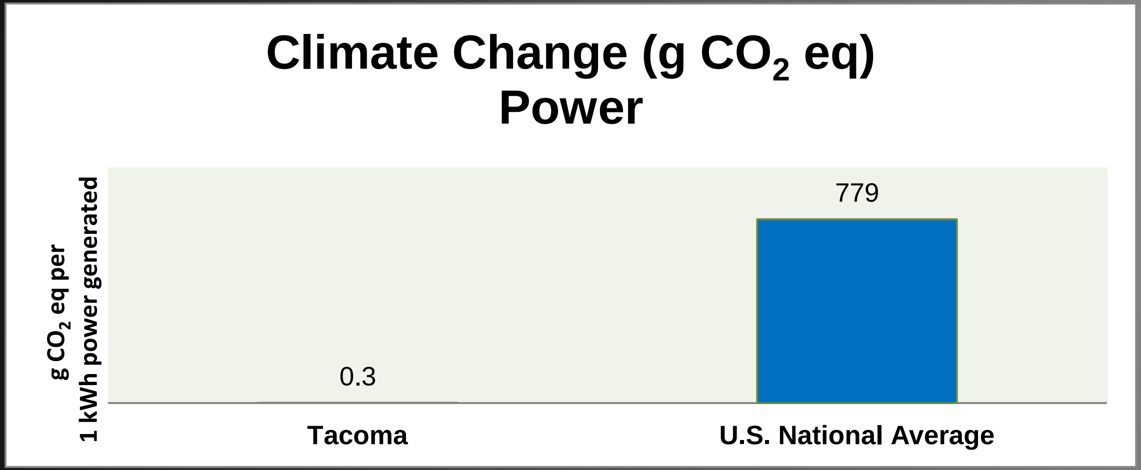
Assumptions/Limitations

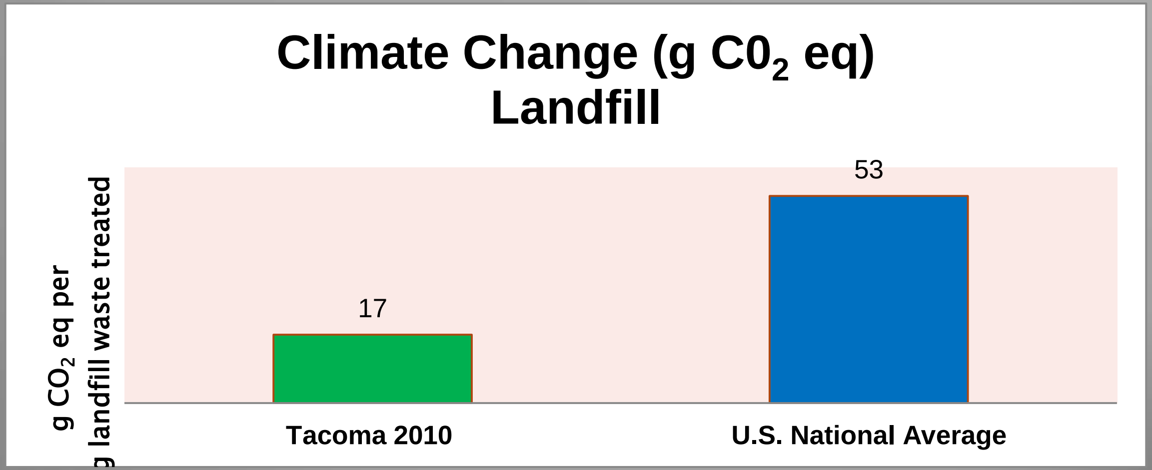
- US average data is data from Switzerland normalized for US electricity grid
- GHG impacts based on Traci II

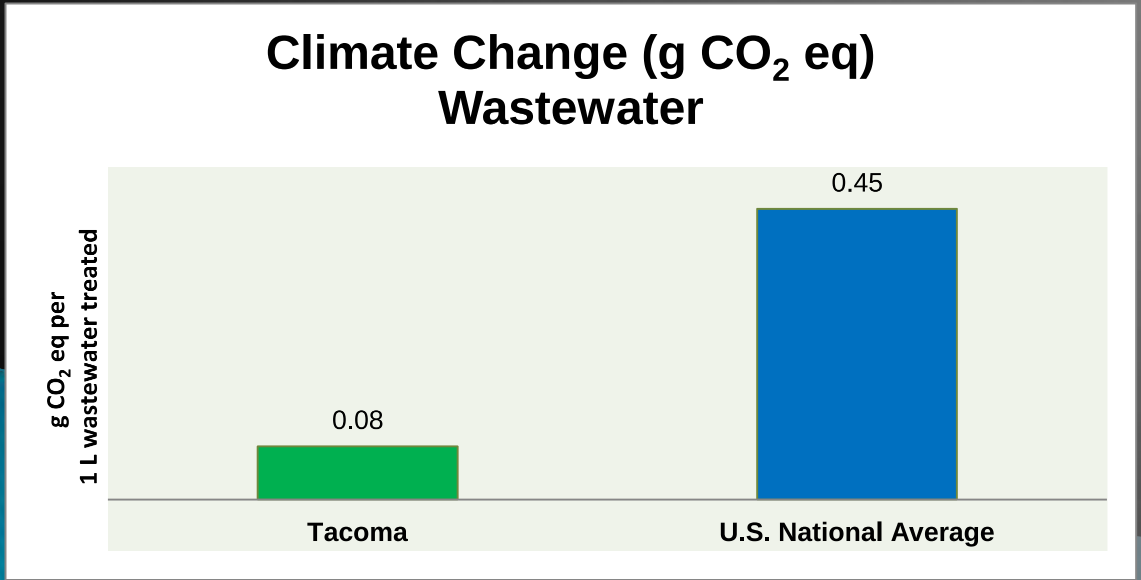
Tacoma and US Power Portfolio

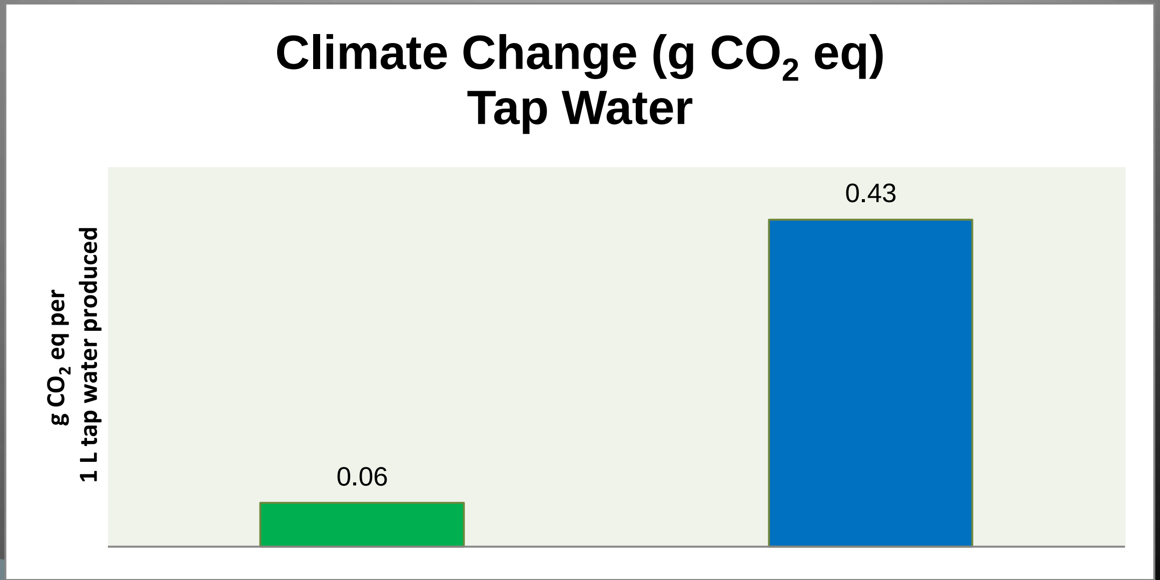


Tacoma Utilities Carbon Footprint









LCA Manager Certificate Classes

- Introduction to LCA
- Communicating LCA Results
- Preparing Your Report for Critical Review

An EarthShift LCA Manager can:

- knowledgeably read LCA reports,
- direct LCA programs and
- apply LCA insights to corporate sustainability programs.

City Search for sustainability decision making tools

- 3 Pillars
  MODA
  Star Community Rating System

History of Sustainable Return on Investment (SROI) Modeling

S-ROI History – early 1990s

- Based on methods and programs developed by GE. "GE developed its new environmental project analysis method to better select and justify waste management investment decisions that are environmentally sound and should reduce long-term liabilities "
- Original concept developed in 1991 by the Tellus Institute for the EPA and New Jersey Department of Environmental Protection and called Total Cost Assessment (TCA)
- Sequence of studies provided the theoretical background for Total Cost Assessment

S-ROI History—1995-2003

- In 1997, AIChE Members wanted a sound TCA methodology
- Embarked on a two-part project.
- Part I: Survey of status and available methodologies world-wide
- Part II : Development of industry validated methodology
- Project Team
  - AD Little (Collab. & Researcher) Bristol-Myers Squibb
  - DOE Dow
  - Eastman Chemical Eastman Kodak
  - Georgia Pacific IPPC of Business Round Table
  - Merck Monsanto
  - Owens Corning Rohm and Haas
  - SmithKline Beecham (Lead) Sylvatica

AIChE® American Institute of Chemical Engineers

S-ROI History 2003—2013

- EarthShift worked with a variety of clients and began developing process around the methodology. Dow Chemical was instrumental
- In 2009, the National Agriculture and Food Research Organization contracted EarthShift to do a series of 4 studies. This resulted in extensive refinement of the methodology and the addition of trandisciplinarity
- In 2012, EarthShift renamed the refined methodology and brought out the 3Pillars S-ROI software tool to reduce resource requirements

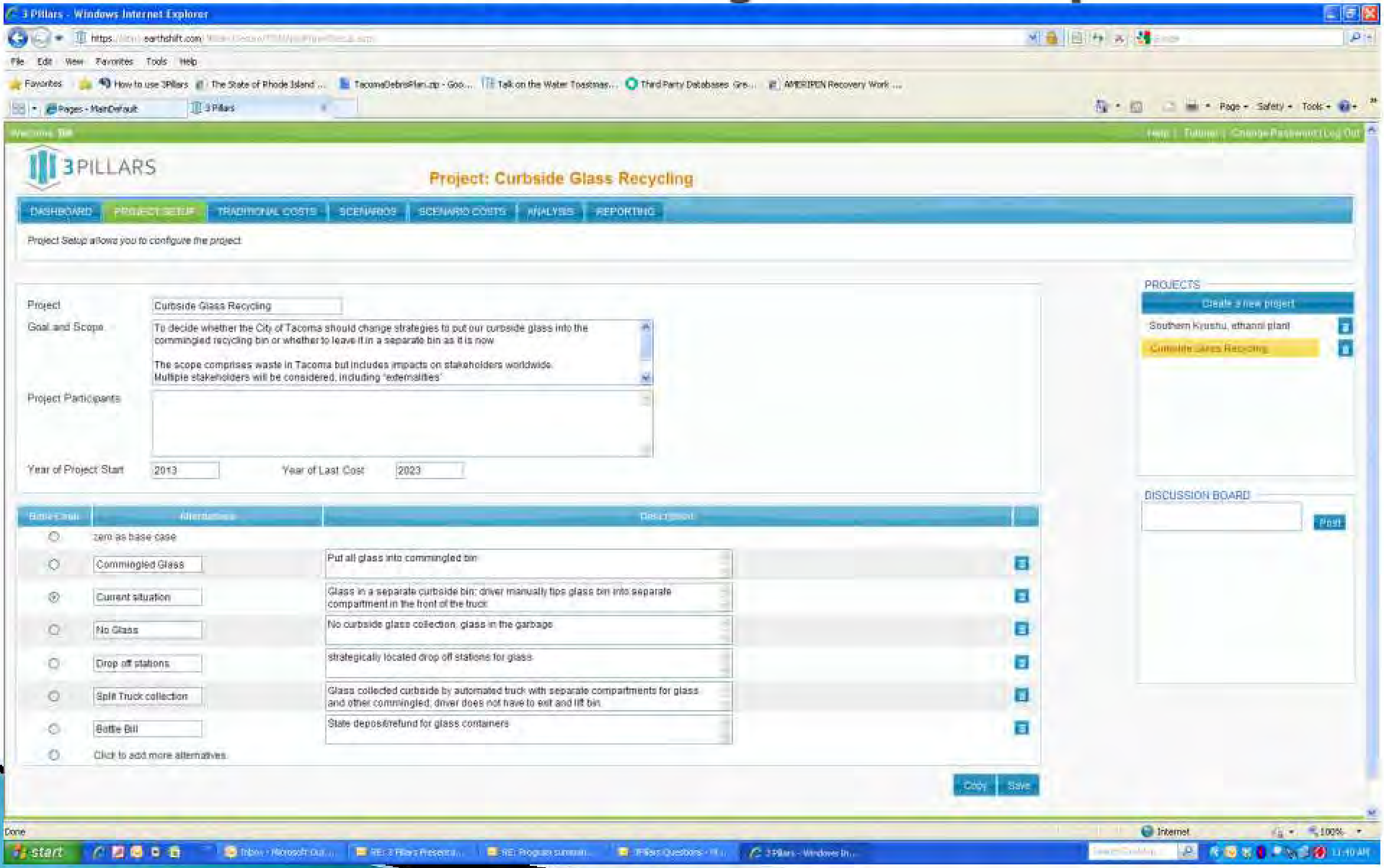
Cost Types

Cost Type	Description	Examples
I. Direct costs and benefits	Manufacturing site costs, revenues	Capital investment, operating, labor, materials, and waste disposal costs, all revenues
II. Indirect costs	Corporate and manufacturing overhead	Reporting costs, regulatory costs, and monitoring costs
III. Future and contingent liability costs and benefits	Potential fines, penalties and future liabilities, potential new legislation	Clean-up, personal injury, and property damage lawsuits; industrial accident costs. Benefits of early implementation.
IV. Intangible internal costs and benefits (Internal)	Difficult-to-measure but real costs (or benefits) borne by the company	Cost to maintain customer loyalty, worker morale, union relations, and community relations. Effects on brand value.
V. External costs and benefits (Societal)	Costs borne by society	Effect of operations on housing costs, degradation of habitat, effect of pollution on human health

Traditional costs

Scenario costs

3 Pillars Project Setup



LLGA
CITIES PILOT THE FUTURE

Living Laboratory Global Awards 2013

- 20 international cities issued challenge to improve urban livability

- Tacoma's challenge was to develop a Sustainable Return on Investment (SROI) calculator.
- The objectives of the SROI tool are to:
  - ensure project and program compatibility with the City's sustainability goals.
  - provide a user-friendly and accessible method to objectively evaluate projects within a consistent framework.
  - be usable throughout the ESU and beyond.
  - be based on LCA principles.
  - provide transparency in terms of assumptions, methods, and criteria.

Multi Objective Decision Analysis (MODA)

- Allows evaluation of economic, societal and environmental criteria
- Can be used for consensus building
- Allows individuals to assign their own weights to the various factors and see where their weights compare with the other evaluators.
- Allows sensitivity analysis for the various decision criteria

Star Community Rating System

What is STAR ?

The STAR Community Rating System is the nation's first framework for evaluating, quantifying, and improving the livability and sustainability of U.S. communities.

The STAR Community Rating System uniquely combines:

- A common framework for sustainability encompassing the social, economic and environmental dimensions of community;
- A rating system that drives continuous improvement and fosters competition; and
- An online tool that gathers, organizes, analyzes, and presents information required to meet sustainability goals

Built Environment	Climate & Energy	Education, Arts & Community	Economy & Jobs	Equity & Empowerment	Health & Safety	Natural Systems
Ambient Noise & Light	Climate Adaptation	Arts & Culture	Business Retention & Development	Civic Engagement	Active Living	Green Infrastructure
Community Water Systems	Greenhouse Gas Mitigation	Community Cohesion	Green Market Development	Civil & Human Rights	Community Health & Health System	Invasive Species
Compact & Complete Communities	Greening the Energy Supply	Educational Opportunity & Attainment	Local Economy	Environmental Justice	Emergency Prevention & Response	Natural Resource Protection
Housing Affordability	Industrial Sector Resource Efficiency	Historic Preservation	Quality Jobs & Living Wages	Equitable Services & Access	Food Access & Nutrition	Outdoor Air Quality
Infill & Redevelopment	Resource Efficient Buildings	Social & Cultural Diversity	Targeted Industry Development	Human Services	Indoor Air Quality	Water in the Environment
Public Spaces	Resource Efficient Public Infrastructure		Workforce Readiness	Poverty Prevention & Alleviation	Natural & Human Hazards	Working Lands
Transportation Choices	Waste Minimization				Safe Communities	

Next Steps

- The City will use 3 Pillars to evaluate two projects:
  - The addition of glass to our commingled recycling stream
  - Purchase of equipment to allow the City to utilize recycled asphalt pavement and recycled asphalt shingles in the City's hot mix asphalt produced at the City-owned asphalt plant
- The City will complete its initial STAR Community Rating in 2013
  - We will obtain our initial achievement level
  - Develop policies, plans and programs to move up the achievement ladder over time

Contact Information

- Bill Smith
- bsmith@cityoftacoma.org
- 253-593-7719

United States
Environmental Protection
Agency

Sustainability Based Decision Making

Tarsha Eason, Ph.D.

Prepared for the West Coast Climate and Materials Management Forum

February 19, 2013

OUTLINE

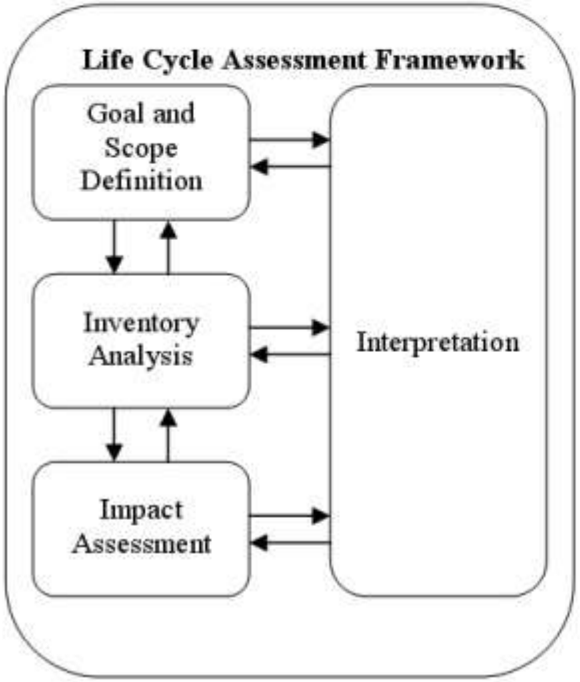
- Life Cycle Assessment
- Sustainability
- Background on Decision Theory/Decision Analysis (DT/DA)
- Key aspects of the Approach
- Resources
- Remarks

United States Environmental Protection Agency

Life Cycle Assessment

- Evaluates the resource inputs, releases and potential **environmental impacts** across a product life cycle
- Aids in avoiding burden shifting and unintended consequences
- Identifies opportunities to reduce environmental burdens system improvements and trade-offs

ISO 14040 and 14044



United States Environmental Protection Agency

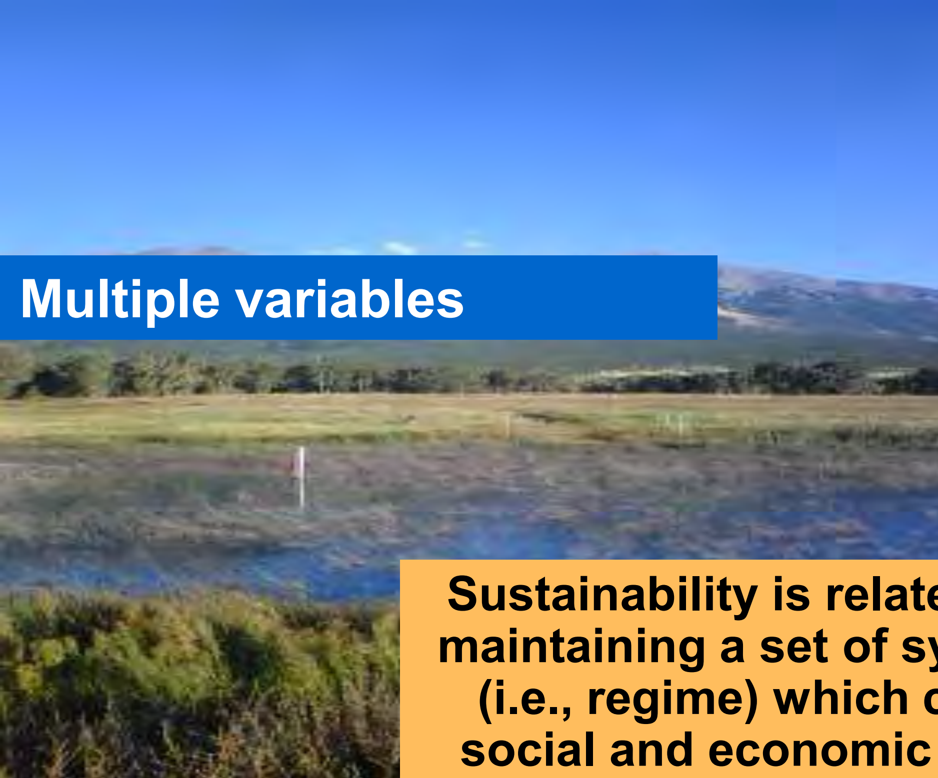
Life Cycle Assessment is only a "piece of the puzzle" in sustainability based decision making

United States Environmental Protection Agency

Sustainability

- World Commission on Environment and Development (1987)
  - "….development that meets the needs of the present without compromising the ability of future generations to meet their own needs"
- National Environmental Policy Act (1969)
  - "… declare[s the development of] a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man….",


Society
Economy
Sustainable
Development
Environment



Multiple variables

Disparate

Sustainability is related to finding and maintaining a set of system conditions (i.e., regime) which can support the social and economic development of human and ecological systems while protecting human health and the environment

Vary over time

Interconnected and Interdependent

EPA United States Environmental Protection Agency

Industry and its environment

- Effect of Human Activities (Graedel 1995)
  - Industry has been successful at developing products and processes to meet the needs of the growing population
  - It has been less adept at identifying some of the long-term consequences of the ways in which it goes about satisfying needs
  - The goal is to make industrial decisions today that will be viewed with favor 20 or 30 years from now
- Dr. Crittenden (2009) highlights
  - The importance of determining pertinent metrics that lead to what can be managed
  - The goal of managing the unavoidable and avoid the unmanageable

United States Environmental Protection Agency

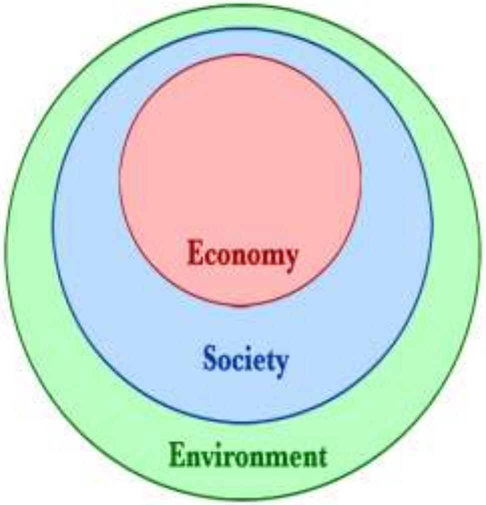
Yesterday's Needs → Today's Problem

MOTIVATION

Consequences of Industrialization

Yesterday's Need	Yesterday's Solution	Resulting Problem
Nontoxic, nonflammable refrigerants	Chlorofluorocarbons	Ozone hole
Automobile engine knock	Tetraethyl lead	Lead in air and soil
Locusts, malaria	DDT	Adverse effects on birds, mammals
Fertilizer to aid Lake and estuary food production	Nitrogen and phosphorus fertilizer	Eutrophication (algal over growth)

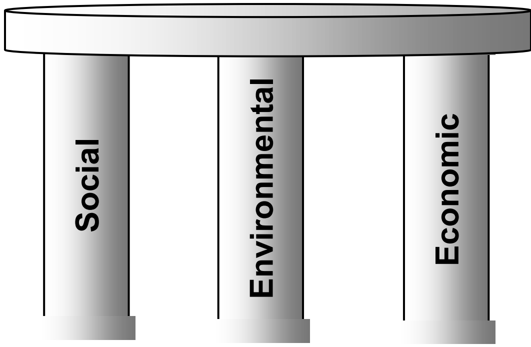
Sustainable Development



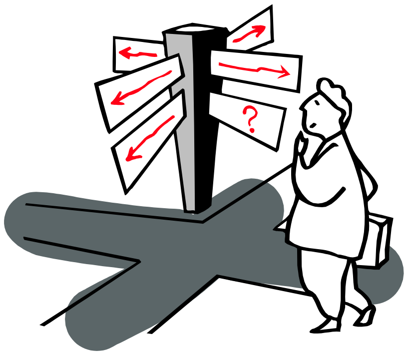
- As noted by the World Commission on Economic Development (WCED), sustainable development which simply stated is meeting present needs without adversely affecting the ability of future generations to meet their needs

- Wackernagel stated that "Sustainability is securing peoples quality of life within the means of nature."

- How is it measured?



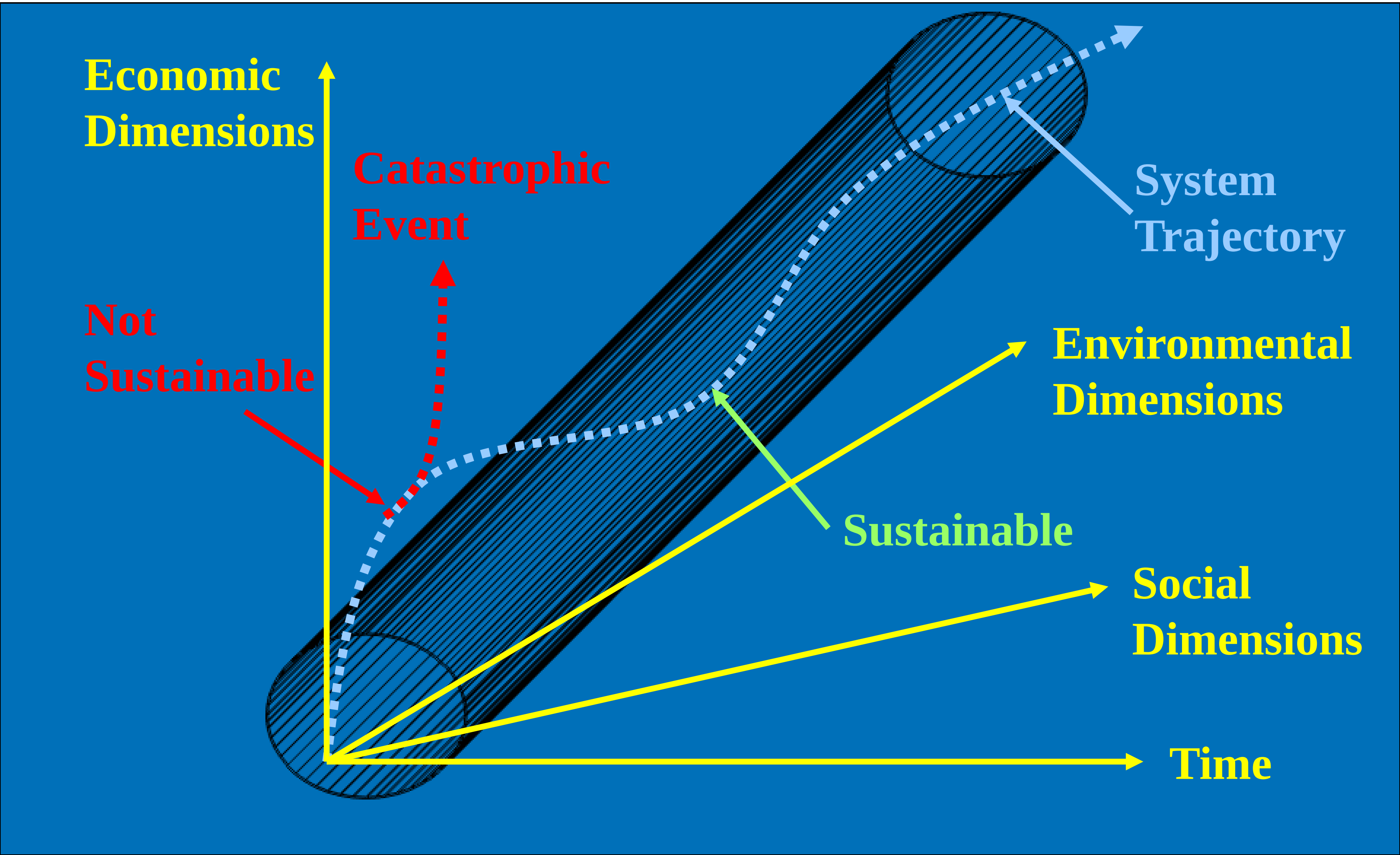
United States
Environmental Protection
Agency



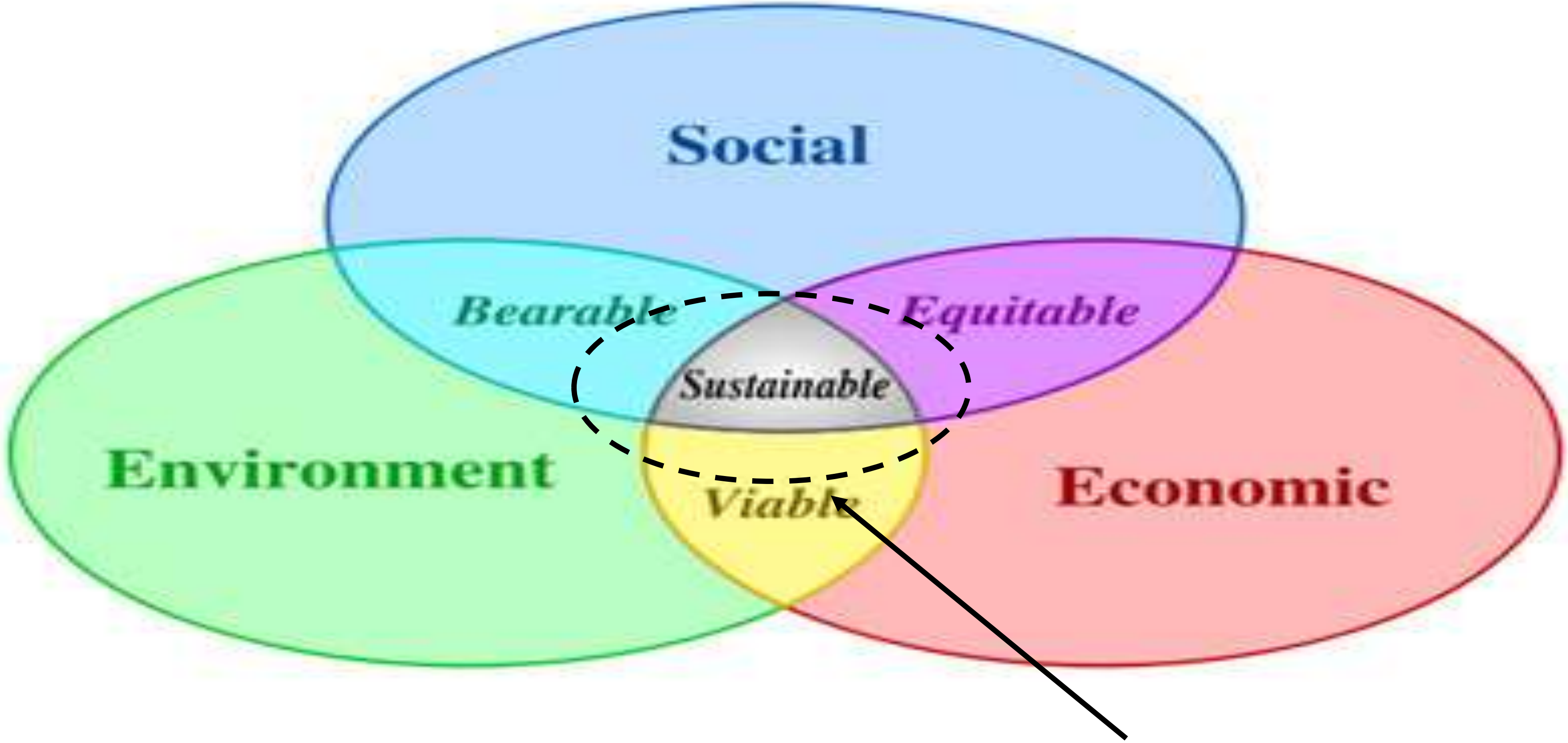
Measuring Sustainability

- Capturing the economic, social and environmental aspects throughout the life cycle
- Indicators and metrics
  - Emissions, resource use, risks, costs, net present value, access to clean water, emergy, exergy, etc.
  - Center for International Earth Science Information Network (CIESIN), Columbia University (2007)
    - Database of 464 Sustainability Indicators
- Real challenge is handling the complexity and reconciling three pillars toward a decision
  - Data quality and availability
  - Complex interactions
  - Disparate nature of sustainability

While optimizing on one aspect is undesirable and may lead to disastrous consequences, recognizing the time-varying nature of systems and solutions is mission critical



Towards Sustainability



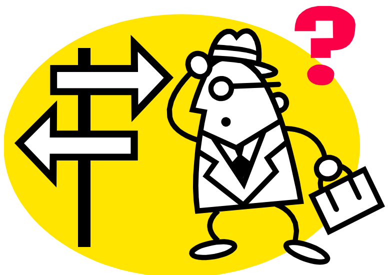
Optimal solutions

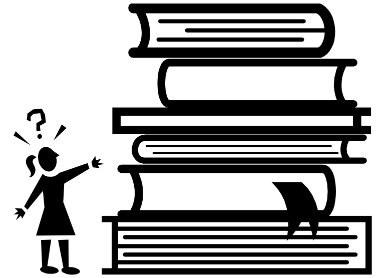
Structure Decision Making

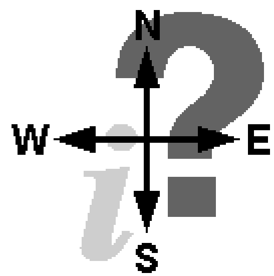
DECISION THEORY AND ANALYSIS

United States Environmental Protection Agency

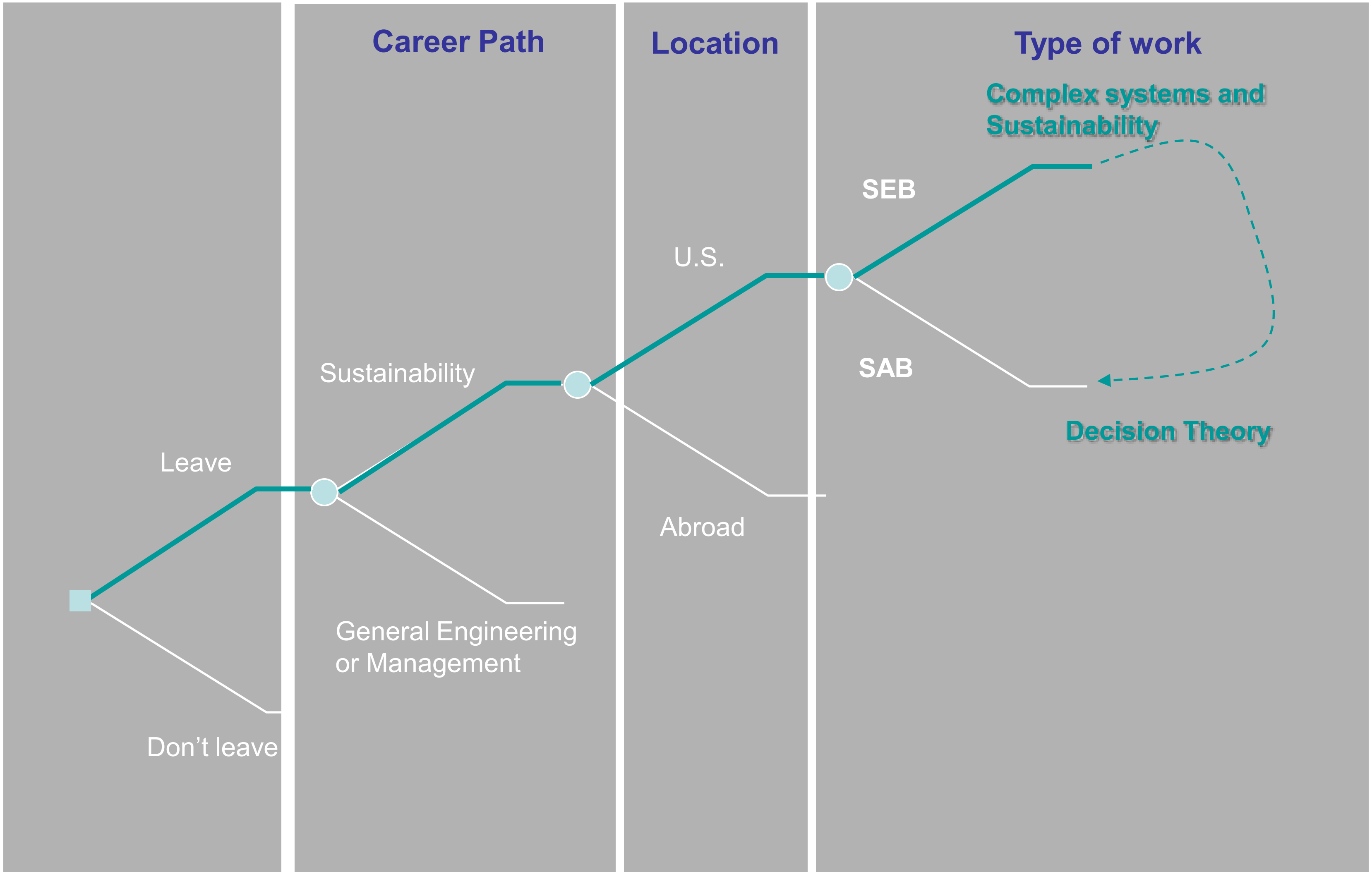
Decisions, Decisions







United States Environmental Protection Agency



United States Environmental Protection Agency

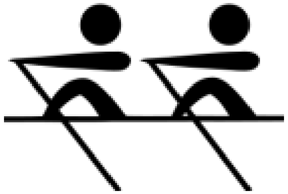
Decision Theory

- Relates to a logical framework of concepts aimed at facilitating decision making
  - Values, risk, uncertainty and tradeoffs
- Interdisciplinary: philosophers, economists, psychologists, statisticians, scientists, engineers, policy makers
  - Descriptive (Experimental psychology)
    - Explain and predict how and why individuals make decisions
      - Changes over time and is impacted by culture, beliefs and desires
  - Prescriptive: Normative
    - Determining the best decision

United States Environmental Protection Agency

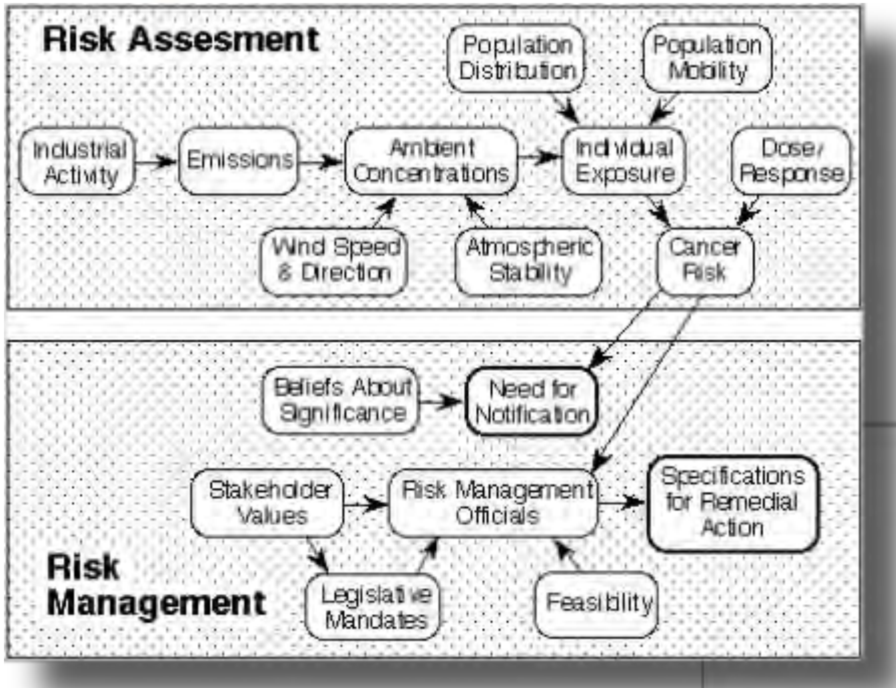
Decision Theory cont'd

- Multiple players (i.e. decision making individuals or entities)
  - Decision making based on the actions of others
  - How to make a collective decision given sometimes conflicting goals, desires and beliefs?....with varying organizational structures and policies?
- Social Choice Theory
  - Establishes principles on decision making between multiple parties (e.g. voting)
- Game Theory
  - Decisions are partially dependant on what other parties do (e.g. chess)
  - Cooperation, collaboration, trust to make a mutually beneficial decision (e.g. rowing), Negotiation



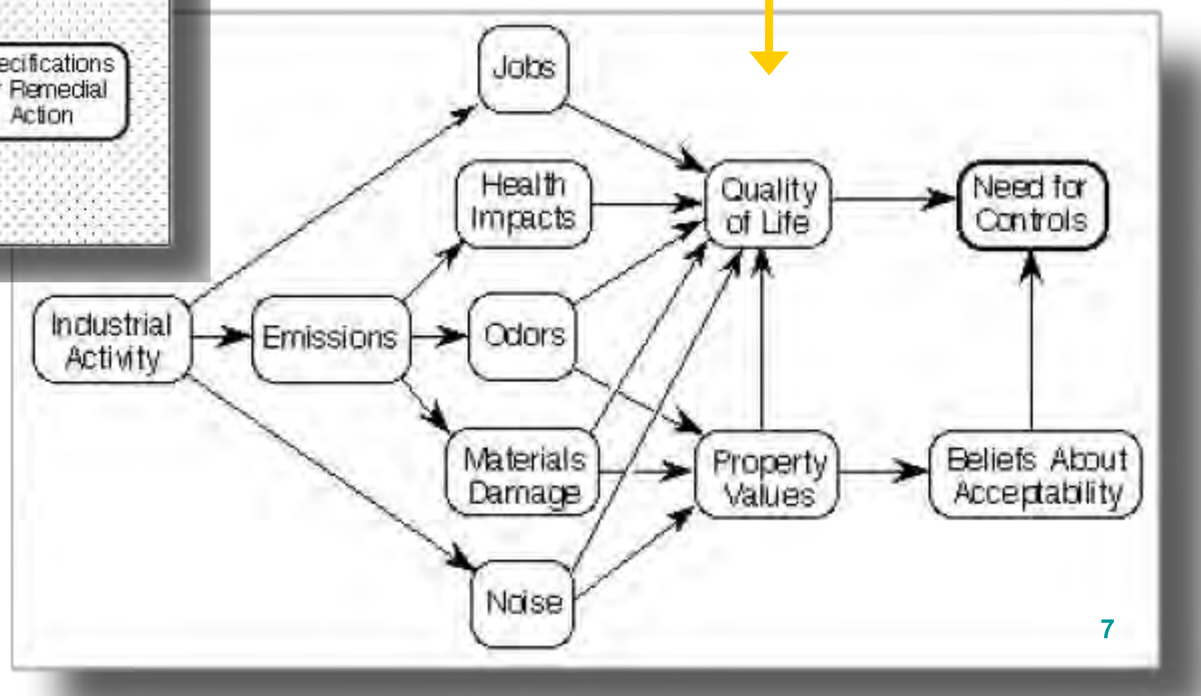
Two men who pull at the oars of a boat, do it by an agreement or convention, tho' they have never given promises to each other (Hume 1739)

Two views, one problem



Regulator's view

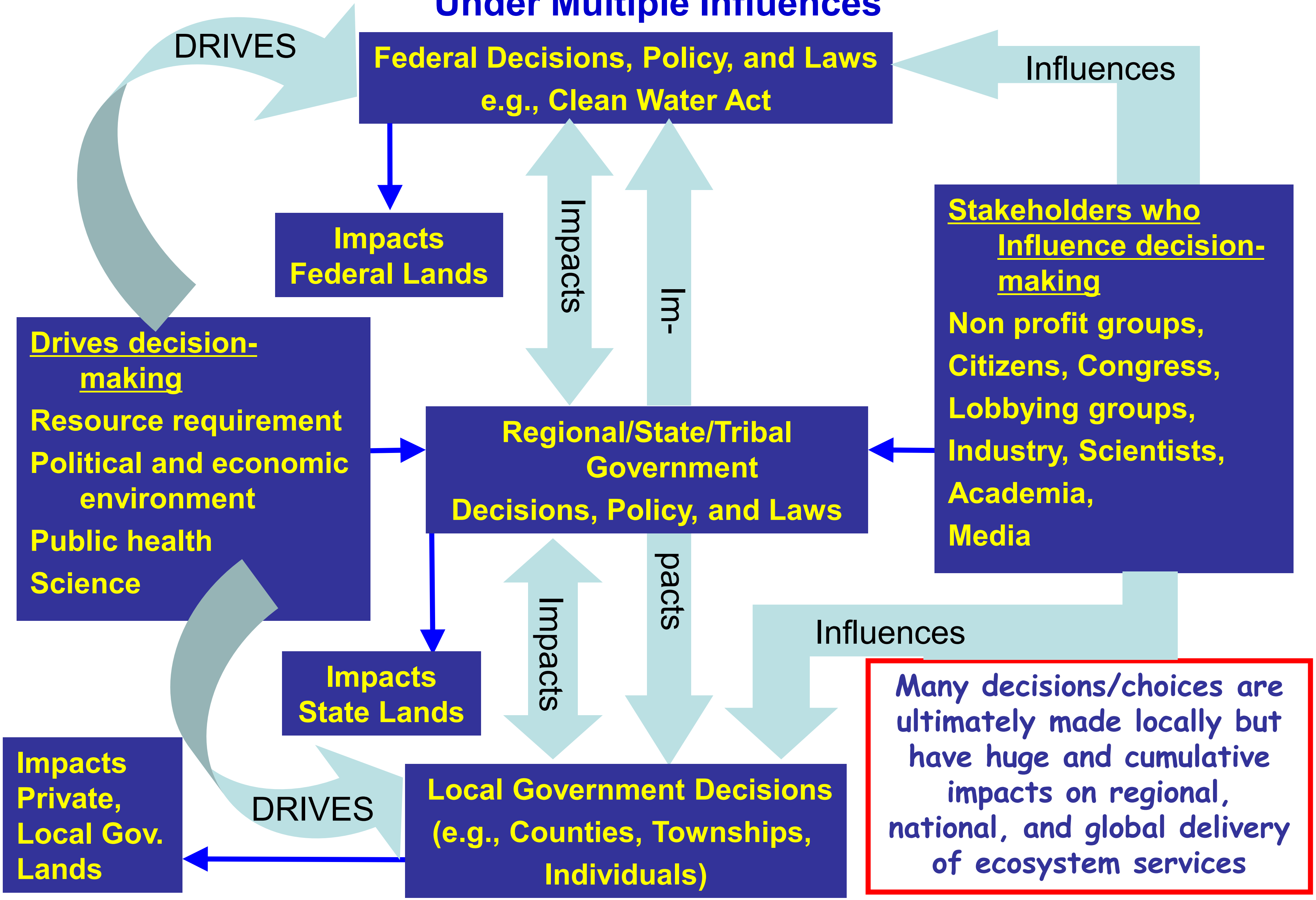
Citizen's view



Keating (1998)

Mitch Small, 2010
ESRP

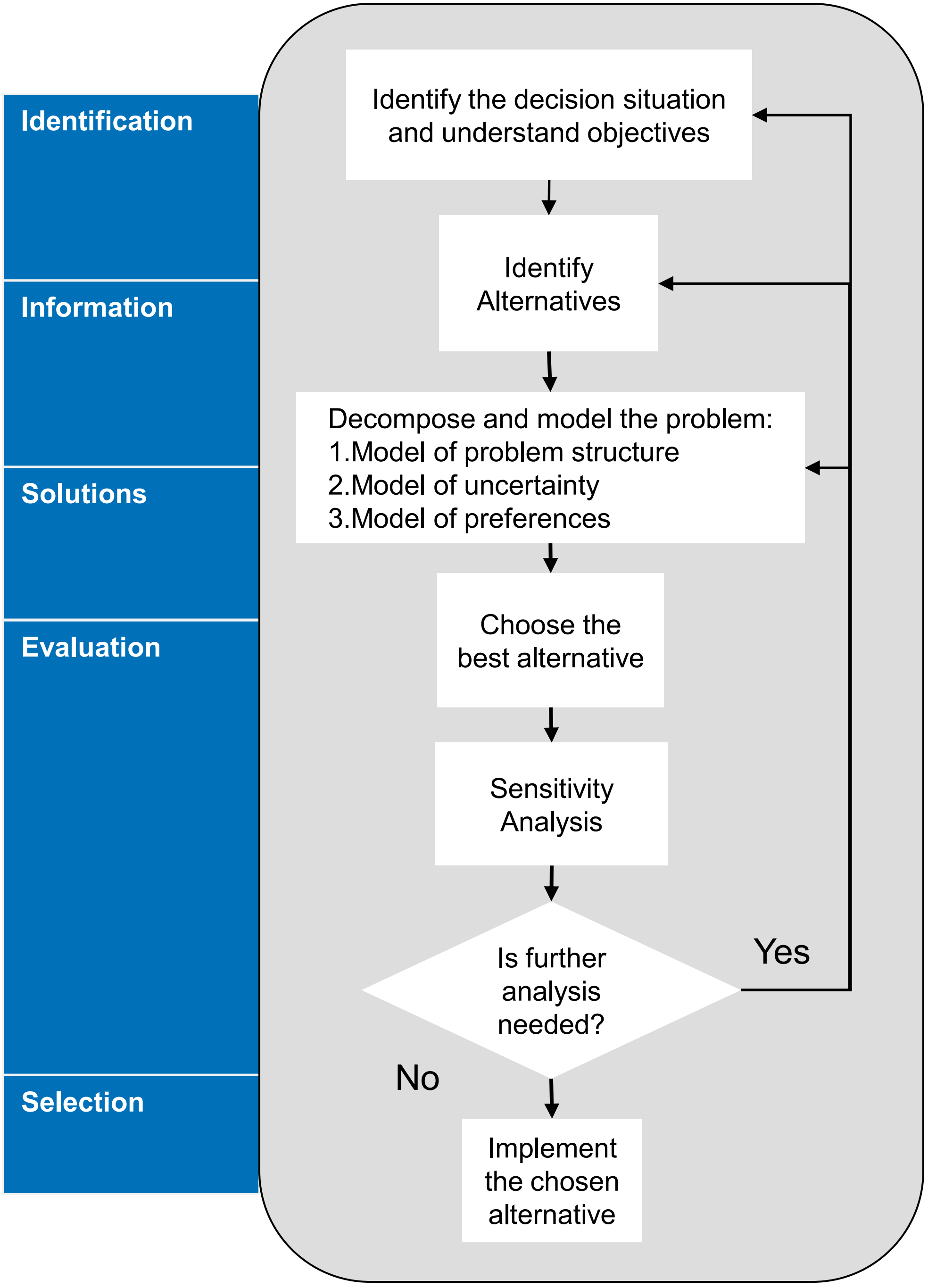
Decision Making Occurs at Multiple Levels, Under Multiple Influences



United States Environmental Protection Agency

Decision Analysis

- Under the banner of normative decision theory
- Systematic approach to helping make difficult decisions
  - Complexity
  - Uncertainty
  - Multiple objectives
  - Different perspectives
- DA aims to aide in understanding the problem to include uncertainty, risks and trade offs
  - Problem Identification
  - Gathering essential information
  - Generating possible solutions
  - Evaluation of solutions
  - Selection of solution

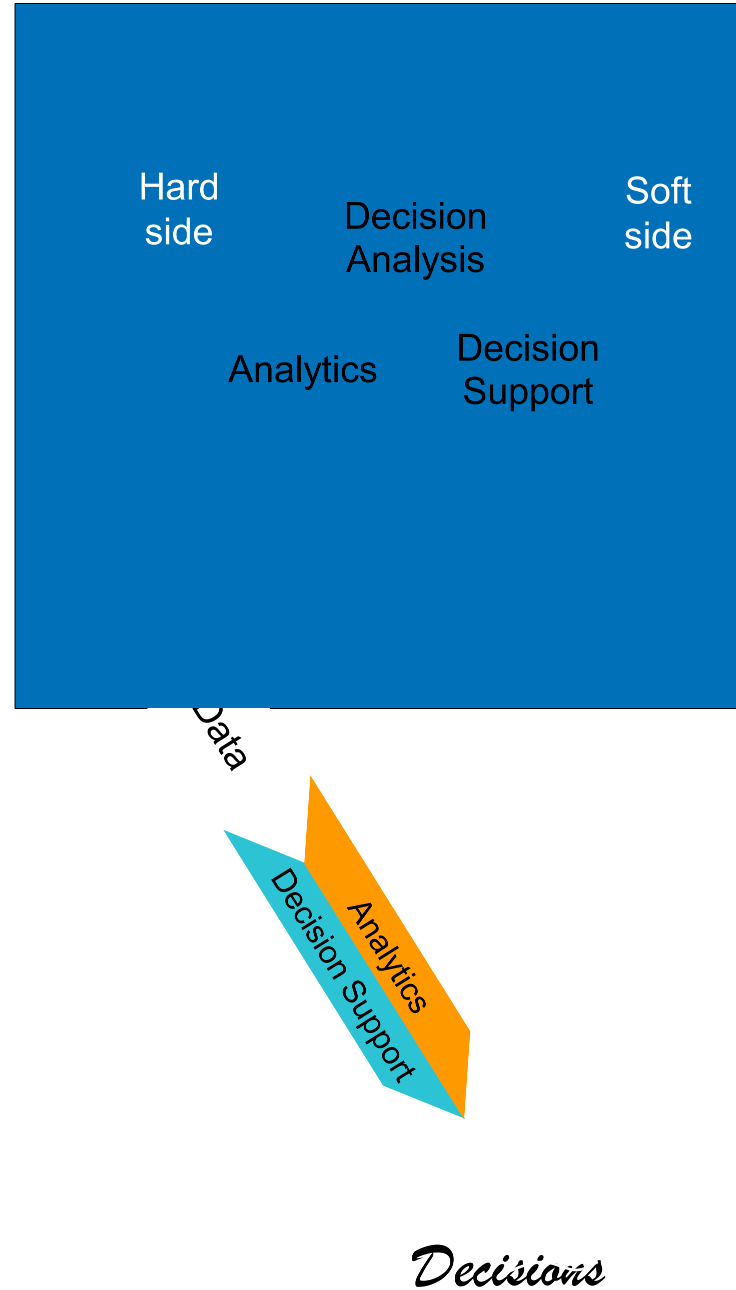


EPA
United States
Environmental Protection
Agency

Decision Analysis

- Hard Side
- Analytics/OR/MS
  - Information and solutions
    - Bench work, Field studies, Experimentation, modeling, optimization, simulation, statistical analysis
    - Indicators and Metrics

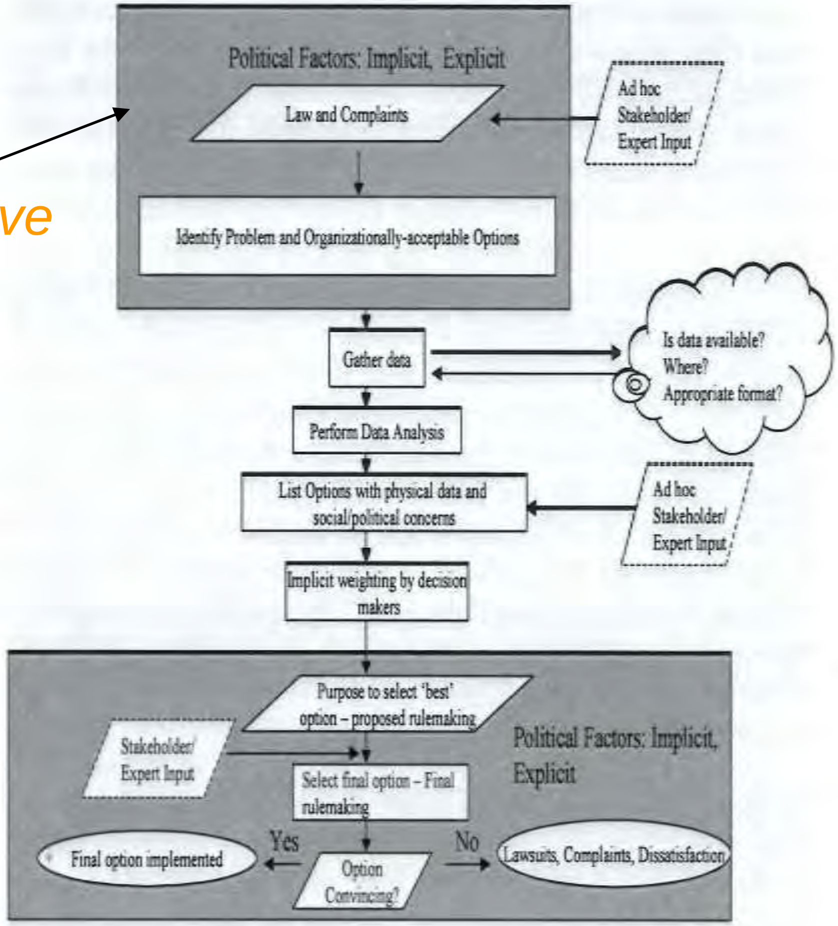
- Soft Side
- Decision Support
  - Identification, Evaluation, Selection
  - Values and Objectives
  - Fishbone diagrams, Pareto, Pair-wise comparison, Value of Information Analysis, Decision-trees
  - Analytic Hierarchy Process, Multi-criteria decision analysis



DA at EPA

- Previously did not recognize stakeholder perspectives
- Influenced by political factors
- Isolates physical and social science
- EPA approaches
  - From typical use of deterministic quantitative multimedia systems to assess costs-benefits to MCDA
  - In 2003, Stahl (10a-b) recommended
    - Multi-criteria integrated resource assessment (MIRA)-developed in EPA region 3

Reactive



United States Environmental Protection Agency

Sample EPA DA/DS tools and methods

- Decision Analysis for a Sustainable Environment, Economy, and Society (**DAASES**) – land and resource decisions
- **GREENSCOPE**- chemical process sustainability
- Database of Sustainability Indicators and Indices (**DOSII**)
- Framework for Responsible Environmental Decision-Making (**FRED**) – LCA tool for product assessment
- **MARK**et **AL**location (**MARKAL**) – energy planning
- Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (**TRACI**) – impact assessment
- **WAR** algorithm – waste reduction for chemical processes
- Planning Land And Communities to be Environmentally Sustainable (**PLACES**) – sustainable land use
- Watershed Central – watershed assessment and management
- Sustainable Management Approaches and Revitalization Tools – electronic (**SMARTe**) – land reuse and revitalization

Sustainability Based Decision Making (SBDM)

APPROACH

EPA United States Environmental Protection Agency

Sustainability based decision making (SBDM)

- EPA has a variety of analysis tools and decision approaches
- However, work is need for existing frameworks and approaches to support sustainability based decisions and assessment, particularly in emerging fields of interest (e.g., nanotechnology)
- This effort is aimed at determining gaps in decision strategies within the Agency by surveying existing methods, approaches and tools and applying key decision theory and analysis methods to develop enhanced mechanisms for sustainability based assessment, development and management of products, processes and systems

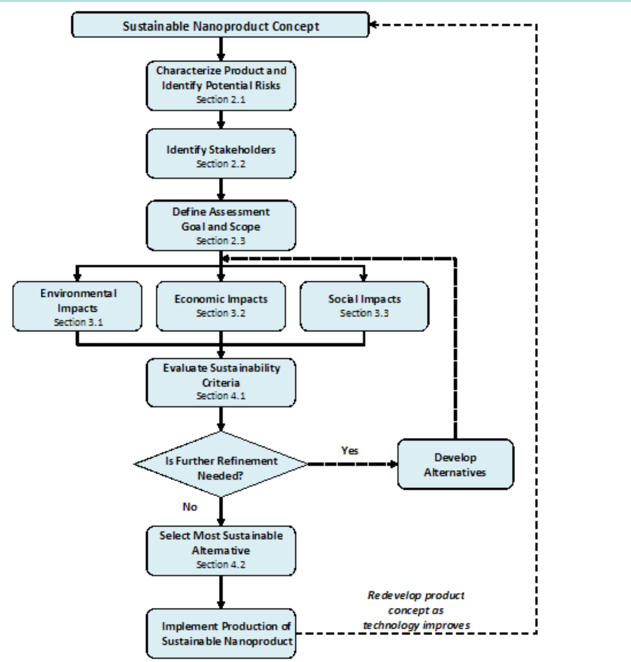
Pertinent Aspects

- Life cycle perspective
- Ensure and promotes a legacy of economic viability, social equity and environmental responsibility for current and future generations
- Characterizes movement toward sustainability
- Methods that support policy where the problem, risk, uncertainty and consequences are well understood
- Stakeholder involvement
- Collaborative ITR
- Proactive rather than reactive
  - e.g. Nano-silver, CNT, bio-fuels
- Incorporates physical and social sciences (DA and DS)
- Systematic approach and holistic view (temporally, spatially, etc.)
- Sensitivity and scenario analysis to understand long term implications

United States Environmental Protection Agency

DSF for Sustainable Nanotechnology

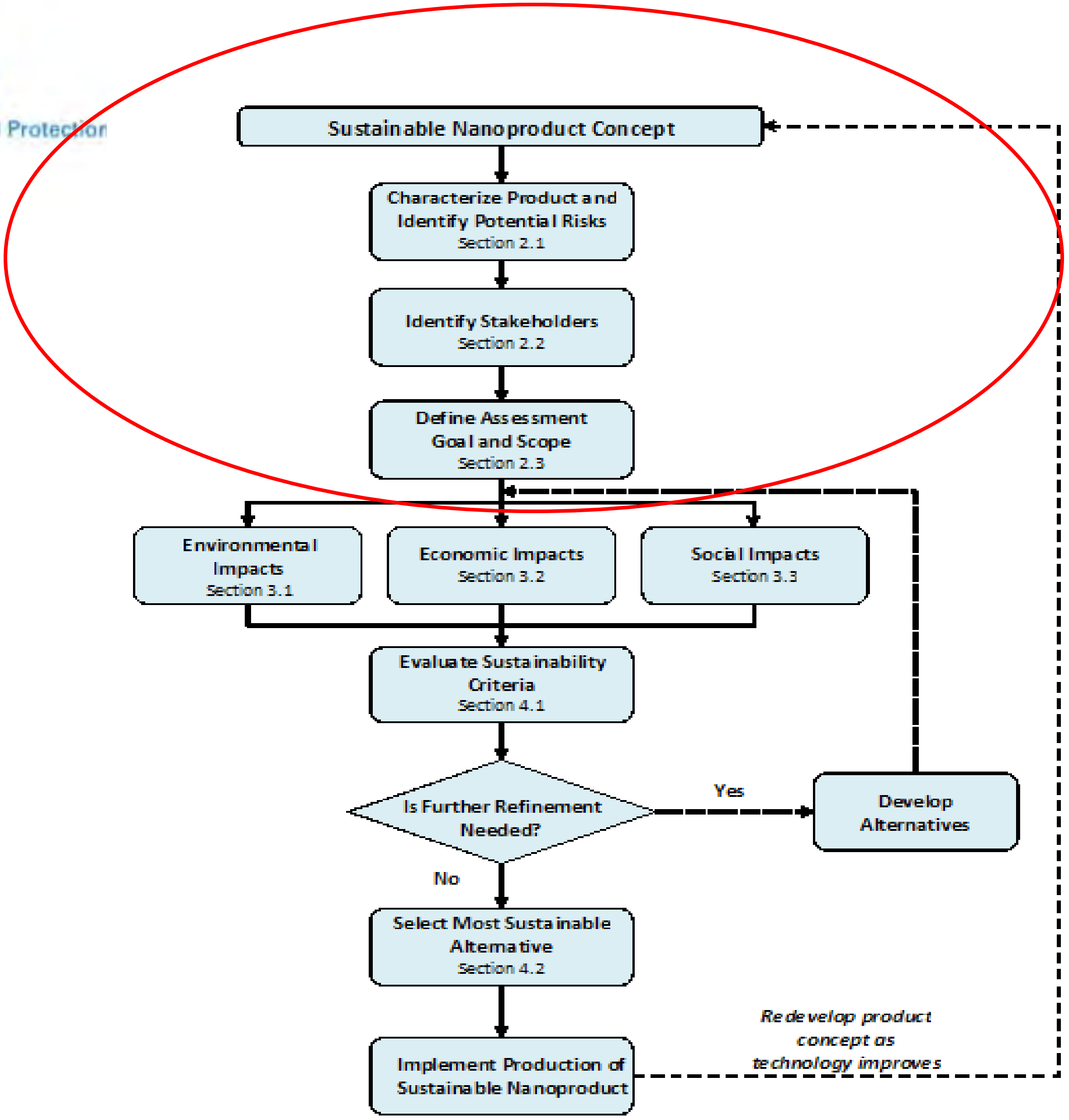
Decision Support Framework for Sustainable Nanotechnology



- Incorporates sustainability into the evaluation, management and development of nanoproducts
- Frames pertinent issues for assessing a nanotechnology from a holistic, life cycle perspective
- Insight on the tools that may be used to assess aspects of sustainability
- Identifies possible DA approaches to integrate data from these disparate evaluations to make quality decisions

Eason, T., Meyer, D., Curran, M.A., and Upadhyayula, V.K., 2011. "Decision Support Framework for Sustainable Nanotechnology Design and Manufacture", EPA Report ■ EPA/600/R-11/107

EPA United States Environmental Protection Agency



EPA United States Environmental Protection Agency

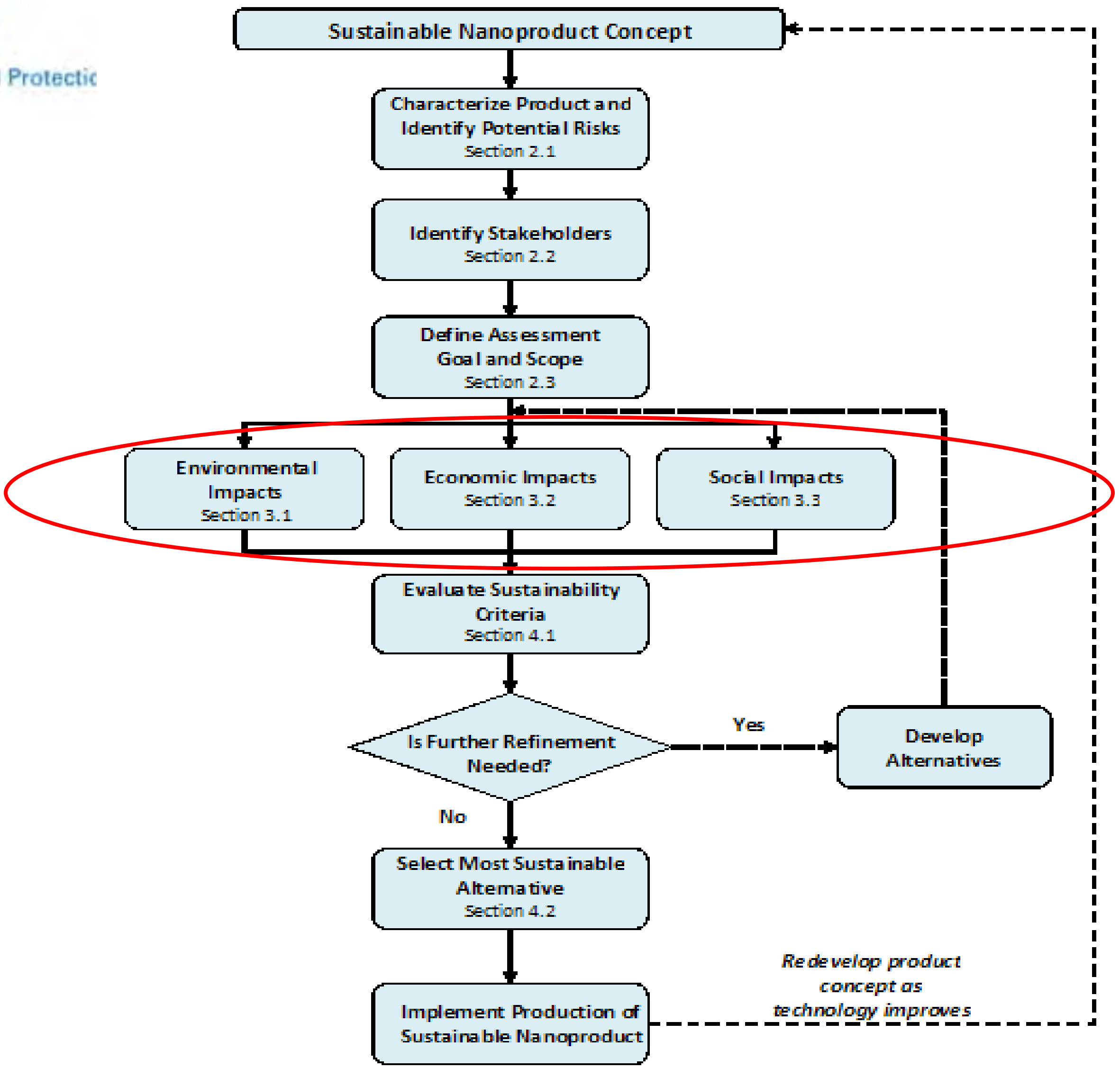
SHC 1.2.2.1 Inventory of Sustainability Indicators and Indices

Sustainability Indicators Database

Indicator	Source	Scale	Country/Org	Pillar	Source Theme	ROE Topic	Program	3V	Dimension
CO2 damage (% of GNI)	World Bank	National	WB	ECO-ENV	National accounting aggregates	Air	ACE	AOI/SCI	2D
CO2 emissions per unit of GDP	World Bank	National	WB	ECO-ENV	Emissions and pollution	Air	ACE	RFI	2D
Particulate emissions damage (% of GNI)	World Bank	National	WB	ECO-ENV	National accounting aggregates	Air	ACE	AOI/SCI	2D
Transport sector energy use per capita	World Bank	National	WB	ECO-ENV	Emissions and pollution	Air	ACE	VCI	2D
CO2 emissions growth	World Bank	National	WB	ENV	Emissions and pollution	Air	ACE	RFI	1D
Carbon Dioxide Emissions - per Capita (CDIAC)	UNEP-GEO Core	Global/National/Regional	UNEP	ENV-ECO	Atmosphere	Air	ACE	SCI/RFI	2D
Carbon Dioxide Emissions - Total (CDIAC)	UNEP-GEO Core	Global/National/Regional	UNEP	ENV	Atmosphere	Air	ACE	SCI/RFI	1D
Concentrations of SO2 and NOx in Major Cities	UNEP-GEO Core	Global/National/Regional	UNEP	ENV	Urban Areas	Air	ACE	SCI/RFI/AOI	1D
Consumption of Ozone-Depleting Substances - Chlorofluorocarbons (CFCs)	UNEP-GEO Core	Global/National/Regional	UNEP	ENV	Stratospheric ozone depletion	Air	ACE	SCI/RFI/AOI	1D
Consumption of Ozone-Depleting Substances - Hydrochlorofluorocarbons (HCFCs)	UNEP-GEO Core	Global/National/Regional	UNEP	ENV	Stratospheric ozone depletion	Air	ACE	SCI/RFI/AOI	1D
Consumption of Ozone-Depleting Substances - Methyl Bromide	UNEP-GEO Core	Global/National/Regional	UNEP	ENV	Stratospheric ozone depletion	Air	ACE	SCI/RFI/AOI	1D
Status of stratospheric ozone	SDI	National	US	ENV		Air	ACE	SCI	1D
(Total/final) energy intensity	RSC	All	UN	ENV-ECO	Energy	Air/Ecological Condition	ACE/SHC	SCI/VCI	2D
Agricultural energy intensities (final energy use per unit of agricultural value added)	RSC	All	UN	ENV-ECO	Energy	Air/Ecological Condition	ACE/SHC	SCI/VCI	2D
CO2 emissions intensity	RSC	All	UN	ENV-ECO	GHG	Air/Ecological Condition	ACE/SHC	SCI	2D
CO2 emissions per capita	RSC	All	UN	ENV-ECO	GHG	Air/Ecological Condition	ACE/SHC	SCI	2D
Energy consumption of transport relative to GDP	RSC	All	UN	ENV-ECO	Energy	Air/Ecological Condition	ACE/SHC	SCI/VCI	2D

- Provides a searchable inventory of peer reviewed sustainability Indicators
- Classified into a single taxonomy system designed to assist EPA's research and management in identifying candidate sustainability indicators and indices relevant to specific sustainability interests.
- Guidance on the selection and use of sustainability indicators
- Resource for internal and external researchers and decision makers
- **Can be used to aid in determining decision criteria for sustainability assessments**

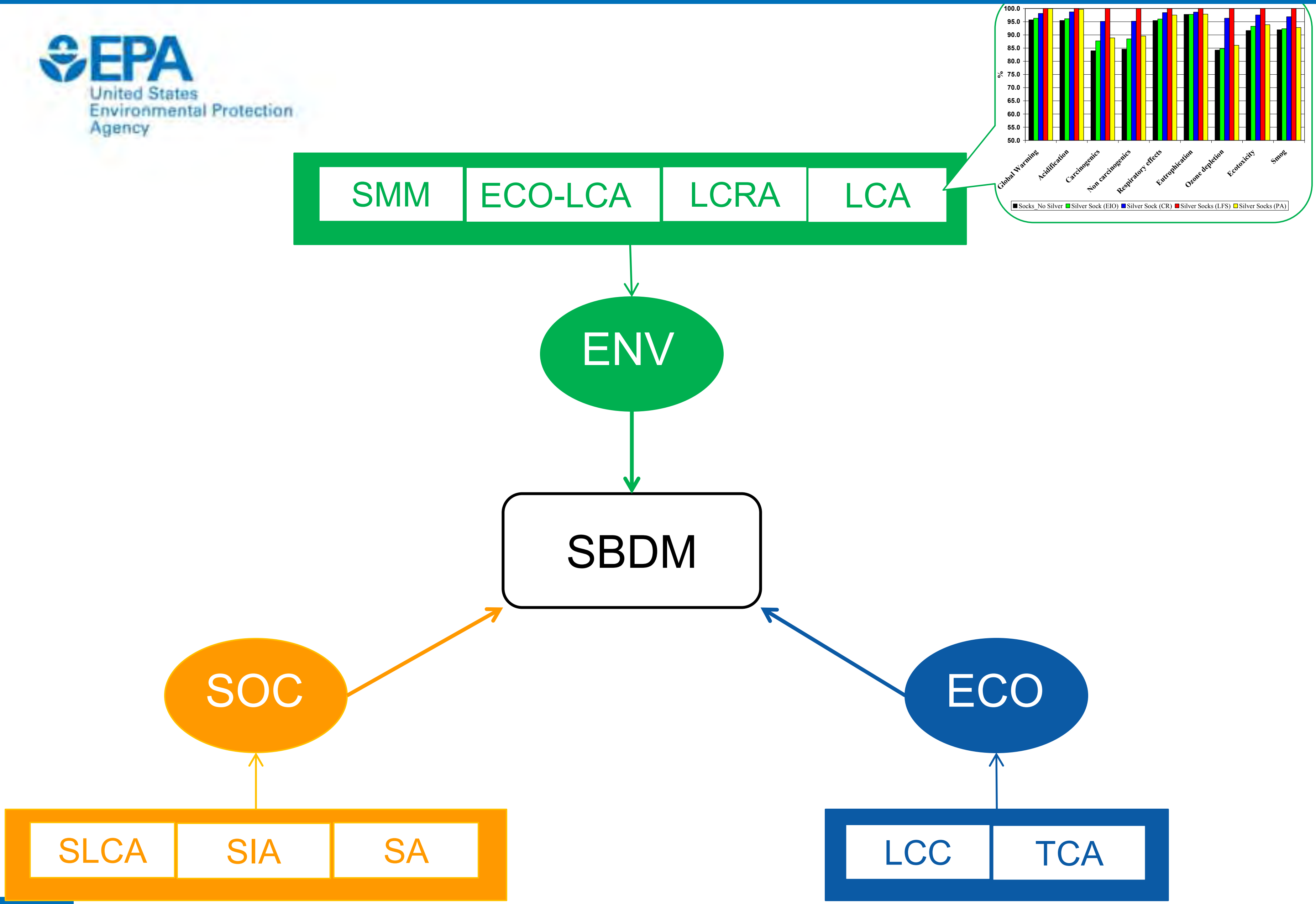
United States Environmental Protection Agency



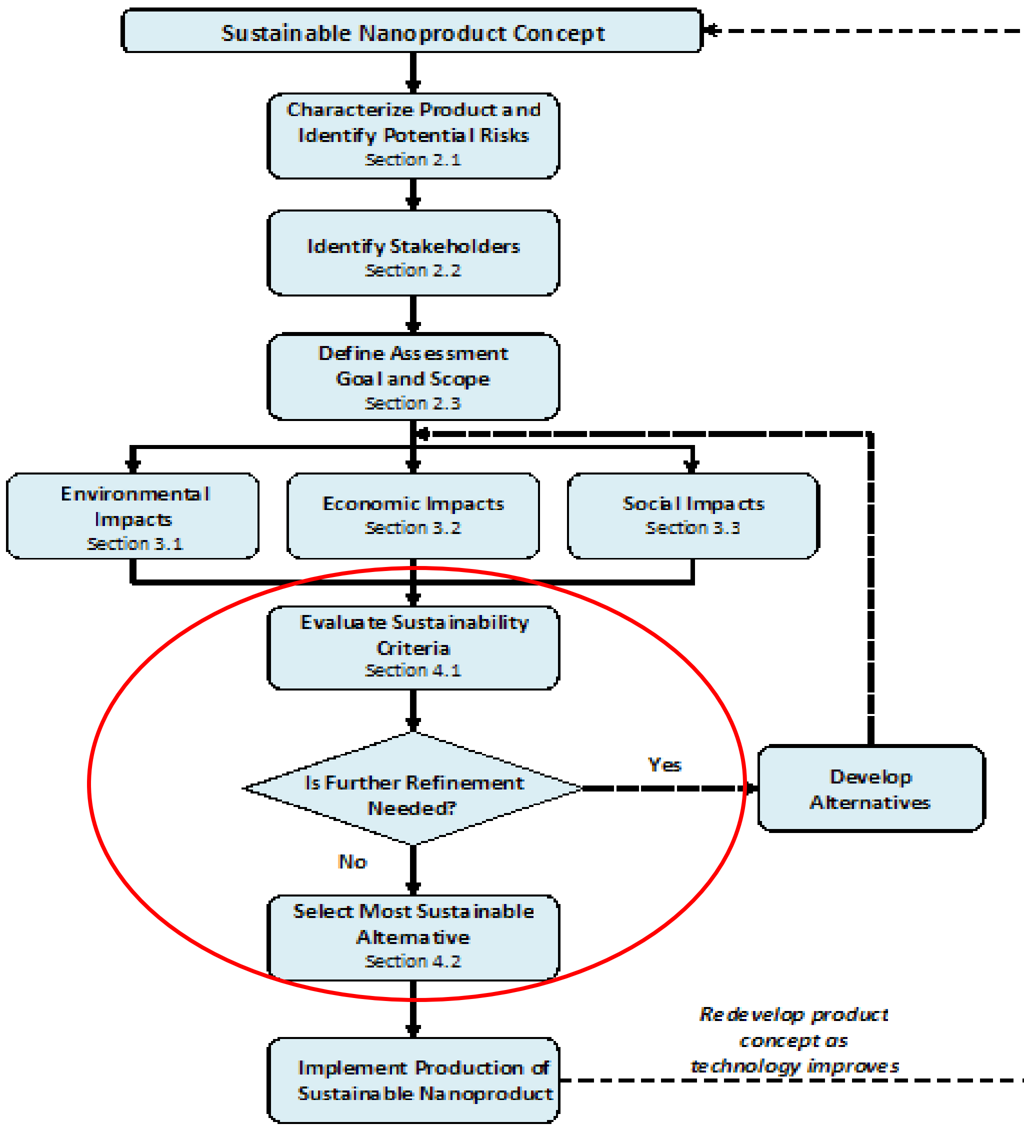
United States Environmental Protection Agency

Environmental Assessment Methods

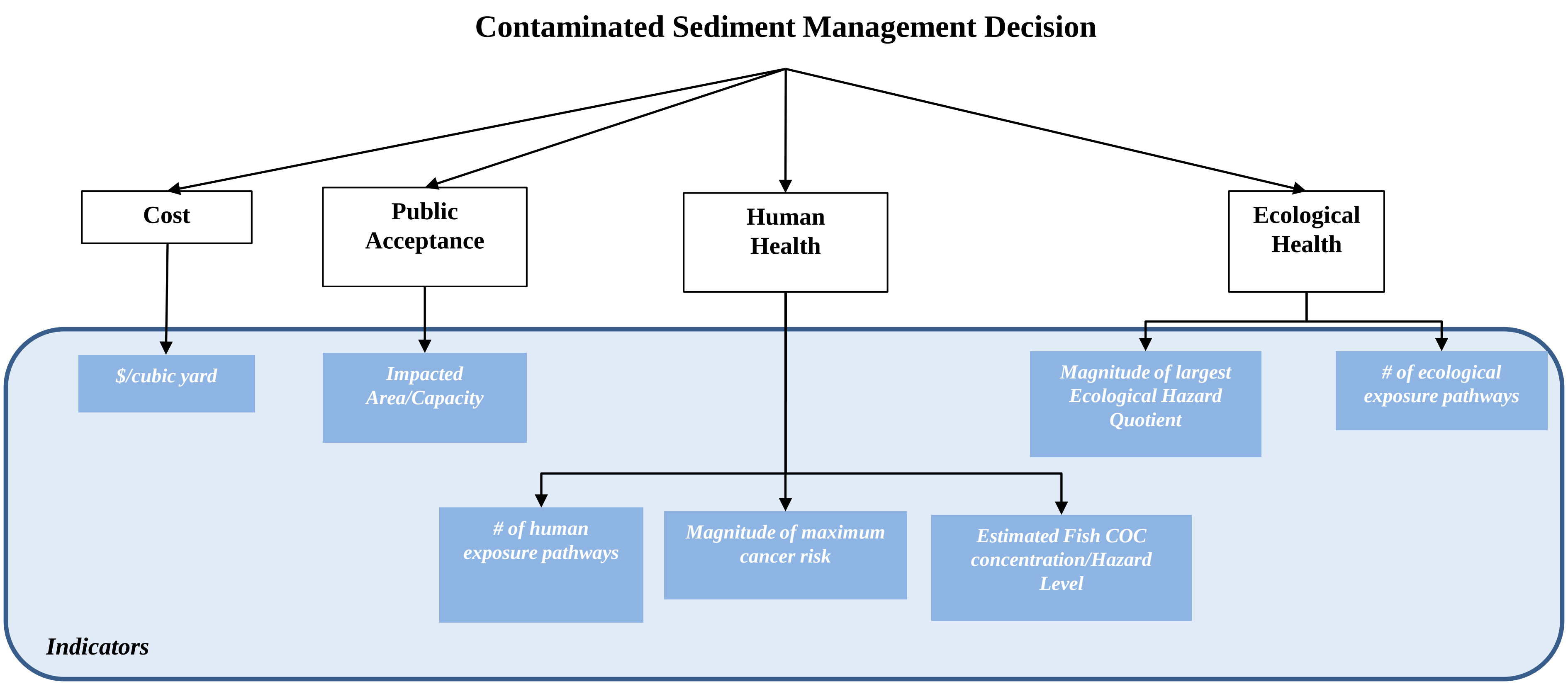
Method	Description/ Benefits	Scope/ Stage	Impacts Measured	Reference
Life-Cycle Assessment (LCA)	Evaluates potential environmental impacts associated with a product, process, or activity. LCAs consider multi-media, multi-attribute impacts by quantifying energy and materials used and wastes released to the environment from cradle to grave.	Product to regional/national level All life cycle stages	• Natural Resource Use (e.g., water, nonrenewables, etc.) • Global warming • Ozone depletion • Smog Formation • Acidification • Eutrophication • Human Health • Ecotoxicity • Land Use • Etc.	(Baumann and Tillman, 2004; EPA, 2006; ISO, 2006; SETAC, 1992)
Carbon Footprint	Both GHG Life Cycle Analysis and Carbon Footprinting aim to account for the release of greenhouse gases that contribute to global climate change. The principal gases are carbon dioxide, methane, nitrous oxide, and fluorinated gases, such as chlorinated fluorocarbons (CFCs).	All life cycle stages	• Carbon • Greenhouse gases • Global warming • Climate Change	(BSI, 2008; WRI, 2010)
Environmentally-Extended Economic Input-Output (EEIO) Life Cycle Analysis	Assesses the economy-wide environmental impacts of a product throughout its life cycle stages. Note that this method may also be used to conduct an economic assessment (see Section 4).	Product/micro level to economy- All life cycle stages	• Economic activity generated • Natural Resource Impacts (e.g., energy use, fuel use, ores, etc.) • Abiotic Ecosystem impacts (e.g., green house gas emissions, ozone depletion, • Toxic releases by sector and chemical	(CMU, 2008a; Klöpffer et al., 2007; Wiedema, 2010)
Life Cycle Risk Assessment (LCRA) e.g., Nano Risk Assessment	Characterizes the nature and magnitude of health risks to humans (e.g., residents, workers, recreational visitors) and ecological receptors (e.g., birds, fish, wildlife) from chemical contaminants and other stressors that may be present in the	Product/local and meso level All life cycle stages	• Health hazards (e.g., neurotoxicity, skin absorption, genotoxicity, etc.) • Environmental (e.g., aquatic, • Safety (e.g., explosivity, reactivity, corrosivity, etc.)	(EPA, 2010; Walsh and Medley, 2007)
Ecosystems Services LCA (ECO-LCA)	Expands upon traditional LCA and quantifies ecosystem services over the life cycle of a product.	Product/micro level to economy-wide level All life cycle stages	Ecological services (e.g., land-use).	(Zhang et al., 2010b; Zhang et al., 2010c)
Sustainable Materials Management (SMM)	Quantifies the relative magnitude of material flows in the global economy. Methods of material flow accounting, such as Material Flow Analysis (MFA) and Total Material Requirements (TMR), are used.	All life cycle stages, with a focus on material extraction and end-of-life management (recycling).	Flows (Kg)	(Fiksel, 2006)


SMM
ECO-LCA
LCRA
LCA
100.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
%
Global Warming
Acidification
Carcinogenics
Non carcinogenics
Respiratory effects
Eutrophication
Ozone depletion
Ecotoxicity
Smog
Socks_No Silver
Silver Sock (EIO)
Silver Sock (CR)
Silver Socks (LFS)
Silver Socks (PA)
ENV
SBDM
SOC
ECO
SLCA
SIA
SA
LCC
TCA

EPA United States Environmental Protectic Agency



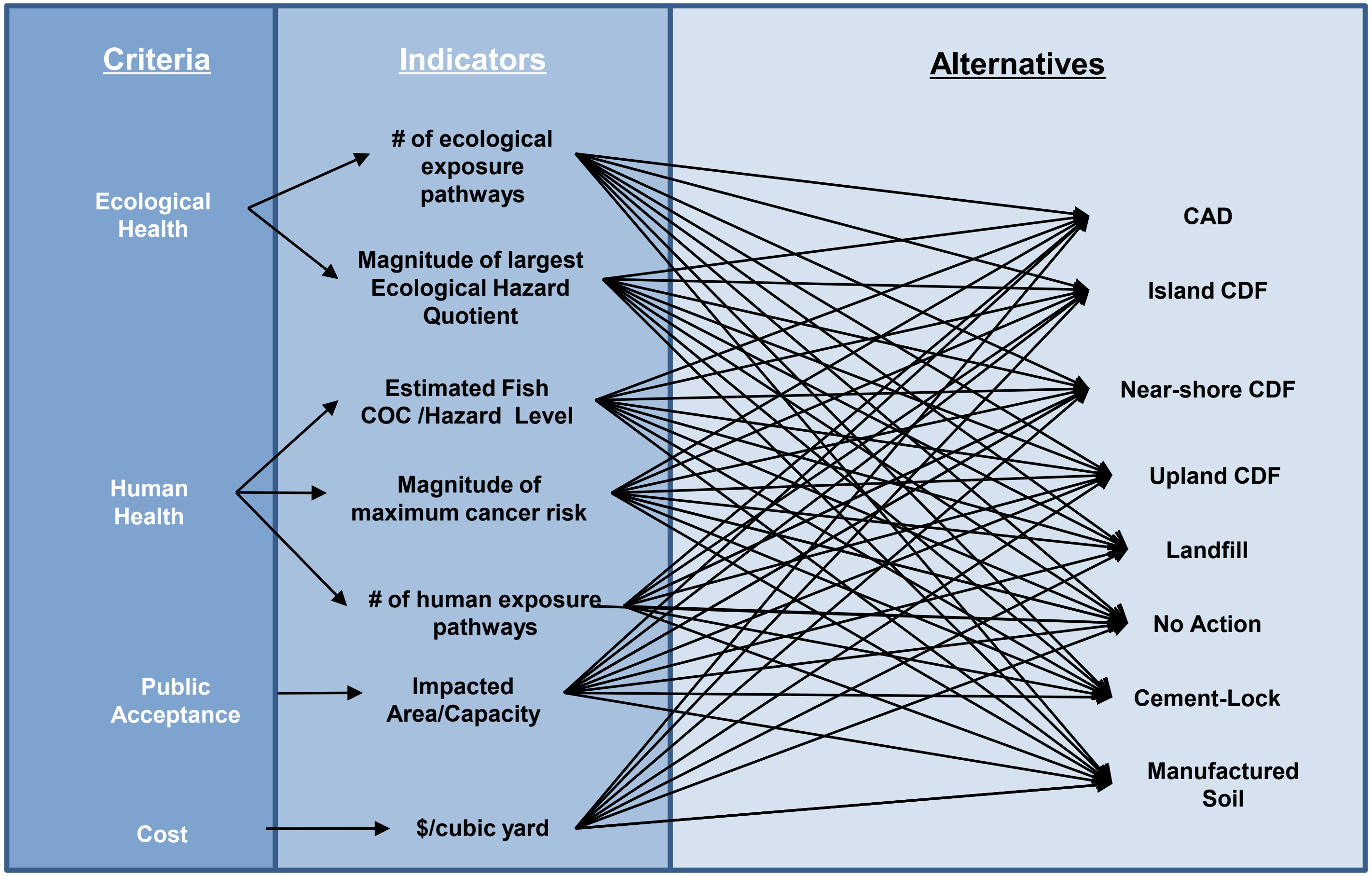
Evaluating Sustainability Criteria



Linkov, I.;Satterstrom, F. K.;Kiker, G. A.;Batchelor, C.;Bridges, T. S.;Ferguson, E., 2006, From comparative risk assessment to multi-criteria decision analysis and adaptive managment: Recent developments and applications. Environment International, 32, (8),1072-1093.

United States Environmental Protection Agency

Evaluating Sustainability Criteria



Disparate Criteria

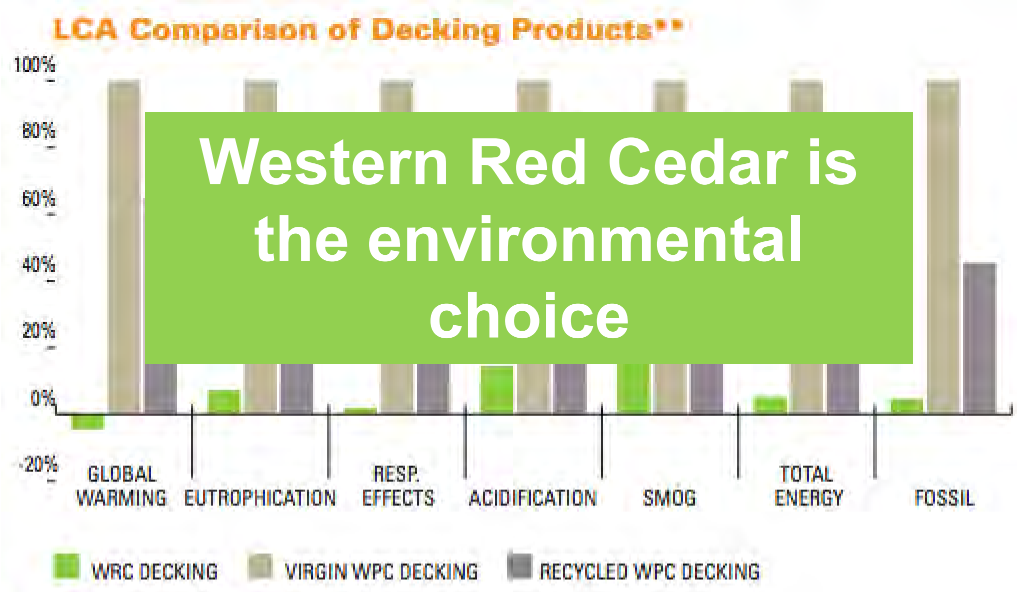
Value choices

Uncertainty

Stakeholder input

United States Environmental Protection Agency

Evaluating Sustainability Criteria



http://www.wrcla.org/cedar_benefits/environment/life_cycle_of_cedar.htm

United States Environmental Protection Agency

Common Decision Analysis Approaches

Elements of decision process	Ad hoc decision making	Probabilistic risk assessment	Multi criteria decision analysis	Cost benefit Analysis
Define problems	Stakeholder input limited or non-existent. Therefore, stakeholder concerns may not be addressed by alternatives	Stakeholder input collected after the problem is defined by decision-makers and experts. Problem definition is possibly refined based on stakeholder input.	Stakeholder input incorporated at beginning of problem formulation stage. Often provides higher stakeholder agreement on problem definition. Thus, proposed solutions have a better chance at satisfying all stakeholders.	Typically defined by decision makers
Generate alternatives	Alternatives are chosen by decision-maker usually from pre-existing choices with some expert input.	Alternatives are generated through formal involvement of experts in more site-specific manner.	Alternatives are generated through involvement of all stakeholders including experts. Involvement of all stakeholders increases likelihood of novel alternative generation.	Alternatives often generated by a limited group of stakeholders and decision makers
Formulate criteria by which to judge alternatives	Criteria by which to judge alternatives are often not explicitly considered and defined.	Criteria and sub-criteria are often defined.	Criteria and sub-criteria hierarchies are developed based on expert and stakeholder judgment.	Evaluation of total expected costs vs. total expected benefits; Criteria often based on various economic meausre to include: net present value, benefit, benefit to cost ratio, etc.
Gather value judgments on relative importance of criteria	Non-quantitative criteria valuation weighted by decision-maker	Quantitative criteria weights are sometimes formulated by the decision-maker, but in a poorly justified manner.	Quantitative criteria weights are obtained from decision-makers and stakeholders.	Preferences are not necessarily made explicit or considered
Rank/select final alternatives	Alternative often chosen based on implicit weights in an opaque manner	Alternative chosen by aggregation of criteria scores through weight of evidence discussions or qualitative considerations.	Alternative chosen by systematic, well-defined algorithms using criteria scores and weights.	Based upon costs and benefits
Strength	Simple and low cost	Systematic means of exploring and quantifying risk; good documentation, quantifies uncertainty, identifies threats	Ability to handle complex decisions with multiple criteria and stakeholders with multiple viewpoints; Decision making in concert with stakeholder values and preferences; strong theoretical foundation; can handle soft issues (e.g., social) and uncertainty	Strong theoretical foundation with tools to aid in estimating (cost and benefits); common unit of measure; helps managers allocate limited resources; not everything can be monetized
Weakness	Inflexible, can not handle complexity or uncertainty, not reproducible, no logic or audit trail, limited stakeholder involvement; therefore, not all concerns considered	Difficult, expensive and time consuming; Possible inaccuracies due to estimating and assumptions on mechanisms that are not well known leading to large uncertainties and misleading results	Typically time consuming	Often limited stakeholder interaction; deals with net impacts and not who pays the costs or reaps the benefits, typically based on market prices and not true preferences

United States Environmental Protection Agency

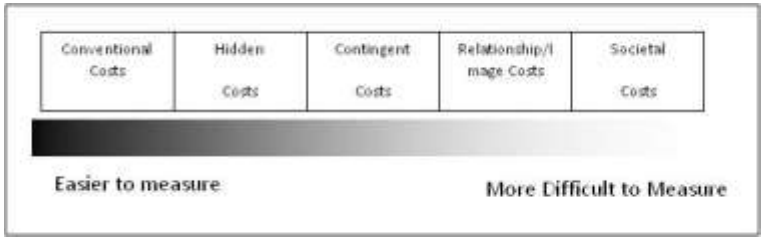
Multi-criteria Decision Analysis approaches

Method	Description	Pros	Cons	Reference	Approaches
Elementary	Non compensatory method with no requirement for quantitatively evaluating criteria trade-offs; Ranking may be based upon: the strength of the weakest or strongest link, attributes meeting predetermined thresholds, or best performance on attributes with t	No weighting is required	Requires attributes to be on a common scale;	(Seppala et al., 2002; Yoon and Hwang, 1995)	Maximin, Maximax, Conjunctive, Disjunctive and lexicographic
Multi-Attribute Utility Theory (MAUT)	Compensatory method in which the overall score for each alternative is based on relative weights; Weights typically determined by surveying stakeholders and generated by utility functions	(1) Easier to compare alternatives whose overall scores are expressed as single numbers. (2) Choice of an alternative can be transparent if highest scoring alternative is chosen. (3) Theoretically sound — based on utilitarian philosophy (4) Many people p refer to express net utility in non-monetary terms.	(1) Maximization of utility may not be important to decision makers. (2) Criteria weights obtained through less rigorous stakeholder surveys may not accurately reflect stakeholders' true preferences. (3) Rigorous stakeholder preference elicitations are expensive.	(Baker et al., 2001; Clemen, 1996; Wolfslehner, 2008)	Multi-value utility theory (MAUT), Simple Multi-Attribute Rating Technique (SMART)
Outranking	Partially compensatory methods that determines the extent to which one alternative dominates another. It allows options to be classified as "incomparable"	(1) Does not require the reduction of all criteria to a single unit. (2) Explicit consideration of possibility that very poor performance on a single criterion may eliminate an alternative from consideration, even if that criterion's performance is compensated for by very good performance on other criteria performance (3) It is easy to explain.	The algorithms used in outranking are often relatively complex and are often not well understood by decision-makers.	(Kiker et al., 2005; Linkov et al., 2007; Naidu et al., 2008a; Seager and Linkov, 2008; Wolfslehner, 2008)	Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE), Elimination Et Choix Traduisant la Realite (ELECTRE) (Kangas et al. 2001) and Novel Approach to Imprecise Assessment and Decision Environments (NAIADE) software
Analytical Hierarchy Process (AHP)	Compensatory method in which the overall score for each alternative based on relative weights. Weights are generated by a series of pair-wise comparisons. . It is the most widely used approach of the MCDA methods.	Surveying pairwise comparisons is easy to implement	The weights obtained from pairwise comparison are strongly criticized for not reflecting people's true preferences	(Huang et al., 2011; Kiker et al., 2005; Linkov et al., 2007; Saaty, 1988; Seager and Linkov, 2008)	AHP

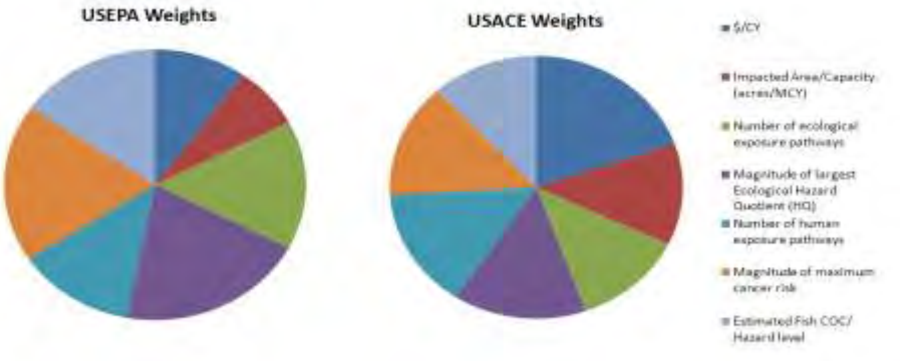
EPA United States Environmental Protection Agency

Other decision making challenges

- **Uncertainty**
  - e.g., Data and data quality
    - LCA is only as good as the underlying data and impact assessment models



- **Valuation and Weighting**
  - Numerical approach to estimating what something is worth based on a value choices and then assigning weights to evaluate trade-offs.



Analytical and decision tools

TIPS AND RESOURCES

United States Environmental Protection Agency

Determining Approach and Selecting Analytical Tools

- Type of System
  - chemical process - e.g. GREENSCOPE
  - ecosystem – e.g. Indicators and Indices
- Objective
  - land and resource decisions - e.g. DAASES
- Time, cost and data availability
  - Screening level and iteratively increase complexity

United States Environmental Protection Agency

Selecting Decision Tools

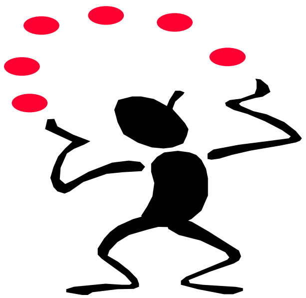
- Stakeholder input
- Time
- Data availability
- Costs (funds allocated)
- Complexity

United States Environmental Protection Agency

Key References and Resources

- CALCAS 2008 D10 SWOT analysis of concepts, methods and models potentially supporting life cycle analysis 037075. Schepelmann, P., Ritthoff, M., Santman, P., Jeswani, H. and Azapagic, A. (eds), Wuppertal Institute for Climate, Environment, Energy, Manchester, UK.
- Eason, T., Meyer, D., Curran, M.A., and Upadhyayula, V.K., 2011. "Decision Support Framework for Sustainable Nanotechnology Design and Manufacture", EPA Report EPA/600/R-11/107
- Eason, T., 2012, Database of Sustainability Indicators and Indices (DOSII), EPA Number: EPA/600/R/12/688
- Fiksel, J., Eason, T. and Frederickson, H., 2012. Framework for Sustainability Indicators at EPA. Eason, T. ed., EPA Report, EPA Number: EPA/600/R/12/687
- Ruiz-Mercado, G.J, Gonzalez, M.A., Smith, R.L., "Expanding GREENSCOPE beyond the gate: a green chemistry and life cycle, Clean Technology and Environmental Policy, October 2012.
- Stockton, T., B. Dyson, W. Houghteling, K. Black, M. Buchholtz ten Brink, T. Canfield, A. Vega, M.Small, A., 2011. Decision Support Framework Implementation of DASEES: Decision Analysis for a Sustainable Environment, Economy, and Society. U.S. Environmental Protection Agency, Cincinnati, OH, EPA /600/R-12/008
- Decision Analysis Tools Database, Contact: Brian Dyson (dyson.brian@epa.gov)

United States Environmental Protection Agency



Concluding Remarks

- Sustainability – our true North
- Sustainability is a highly complex issue
- Premium on research that informs, enables, and empowers sustainable solutions (A.A. Paul Anastas)
- Data, analytics and decision support drive decisions
- Must understand the risk, uncertainty and time-varying nature of decisions
- Methods that help move us toward sustainability and provides outputs that lead to management options

Linking ORD research to inform management., policy and development through sound decision mechanisms and approaches

Contact Information

Tarsha Eason, Ph.D.

U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
Sustainable Technologies Division
System Analysis Branch
26 West Martin Luther King Drive, MS483
Cincinnati, Ohio 45268

eason.tarsha@epa.gov

United States Environmental Protection Agency

Disclaimer

The opinions expressed in this presentation are those of the author. They do not reflect EPA policy, endorsement, or action, and EPA does not verify the accuracy or science of the contents of this presentation. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. Links to non-EPA websites do not imply any official EPA endorsement of or a responsibility for the opinions, ideas, data, or products presented at those locations or guarantee the validity of the information provided. Links to non-EPA servers are provided solely as a pointer to information that might be useful to EPA staff and the public.