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NIST

Why Measure Sustainability?

- A COMPREHENSIVE REVIEW AND FUTURE APPLICATIONS

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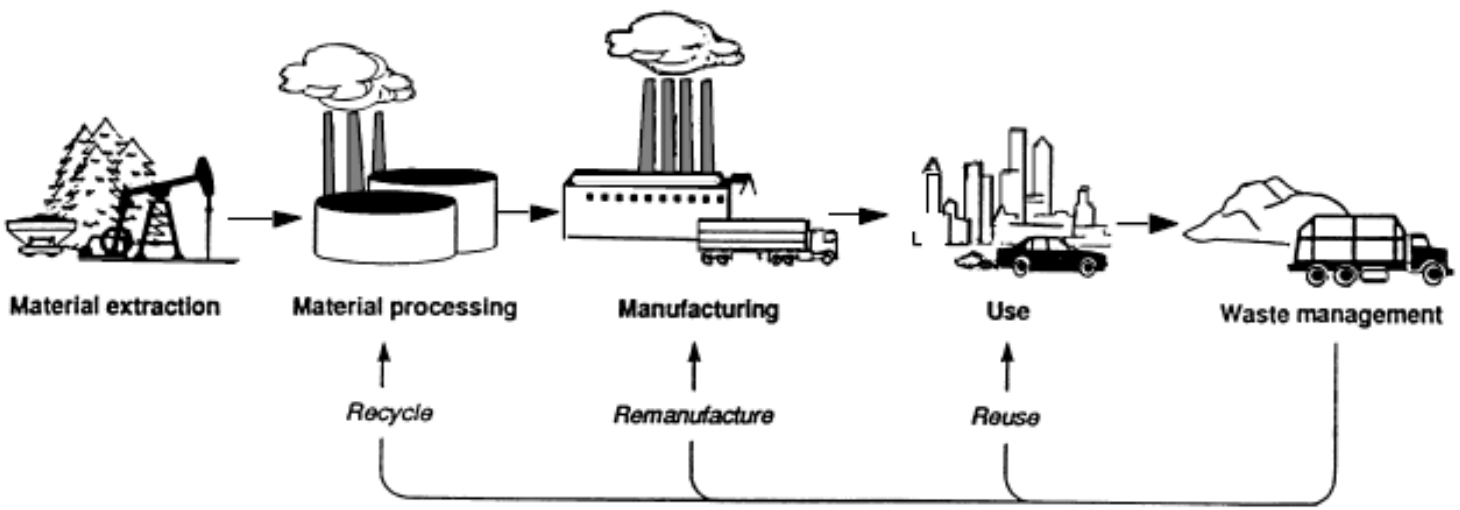
Introduction

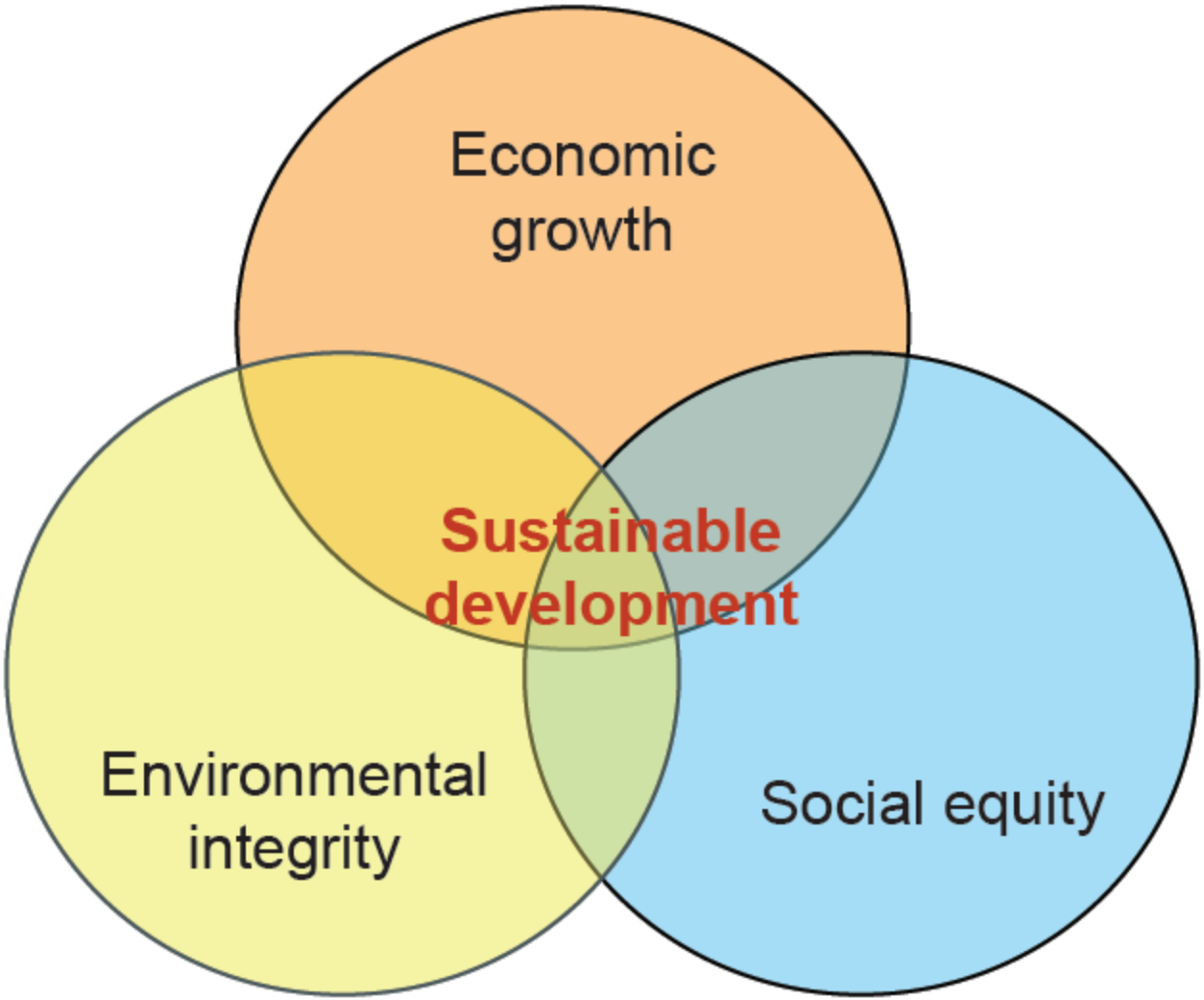
Sustainable Manufacturing is…

"Sustainable manufacturing is defined as the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound." — **U.S. Department of Commerce Definition**



Source: US Office of Technology Assessment (1992)

Sustainable Development



ISO Standard and Sustainable Development

Examples:

- The ISO 14000 series on environmental management
- ISO 14064 and 14065 on GHG accounting and verification
- ISO 21930: Sustainability in building construction -Environmental declaration of building products
- ISO/TC 224 on water supply and treatment services
- ISO initiatives on energy efficiency and renewable sources (e.g. bio-fuels, energy management…)
- ISO/TC 197 on hydrogen technologies
- ISO/TC 85 on nuclear energy
- ISO/TC 8 new work on ship recycling

Source: IQNET- APCER Forum 2007

ISO Standard and Sustainable Development

Examples:

- ISO/COPOLCO Guidelines for developing standards related to child safety, older persons and persons with disabilities
- ISO/TC 199 on safety of machinery
- ISO/TC 94 on protective equipment
- ISO/TC 159 on ergonomics, possible OHSMS work with ILO
- The ISO/IEC 19794 series on biometric data interchange formats
- The ISO 28000 series on security management in the supply chain
- ISO 13485 -Quality management system for medical devices
- ISO/TC 215 on health informatics

Source: IQNET- APCER Forum 2007

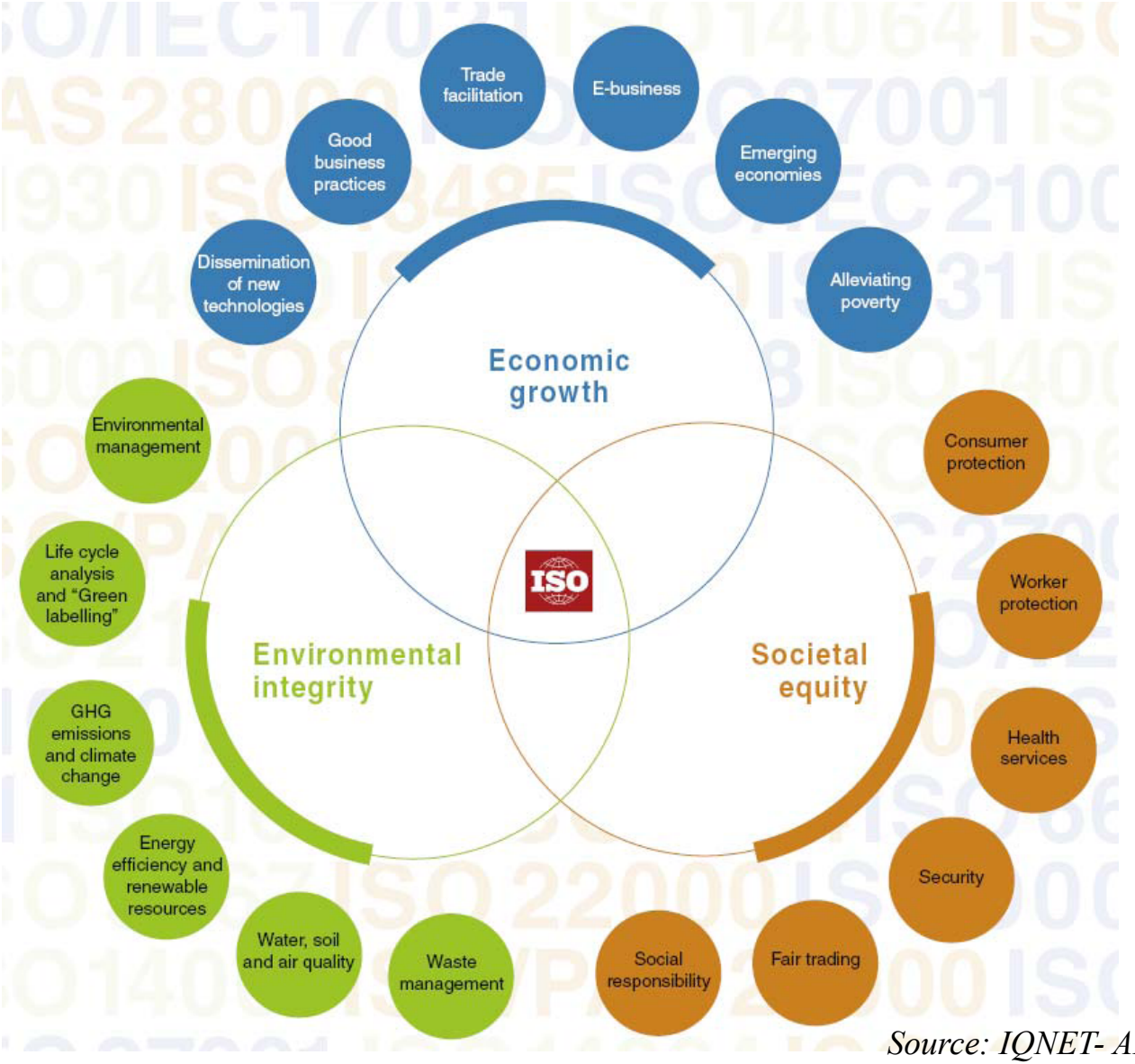
ISO Standard and Sustainable Development

Examples:

- The ISO 9000 series for quality management
- The ISO/IEC 17000 series for conformity assessment
- Numerous ISO standards for industry: energy, aerospace, automobile, building, industrial equipment, IT…
- ISO/TC 229 on nanotechnologies
- IEC/ISO/ITU cooperation (e.g. digital car, digital home)
- ISO standards for e-business
- Data processing and exchange: JPEG, MPEG, PDF, XML…

Source: IQNET- APCER Forum 2007

ISO Standard and Sustainable Development

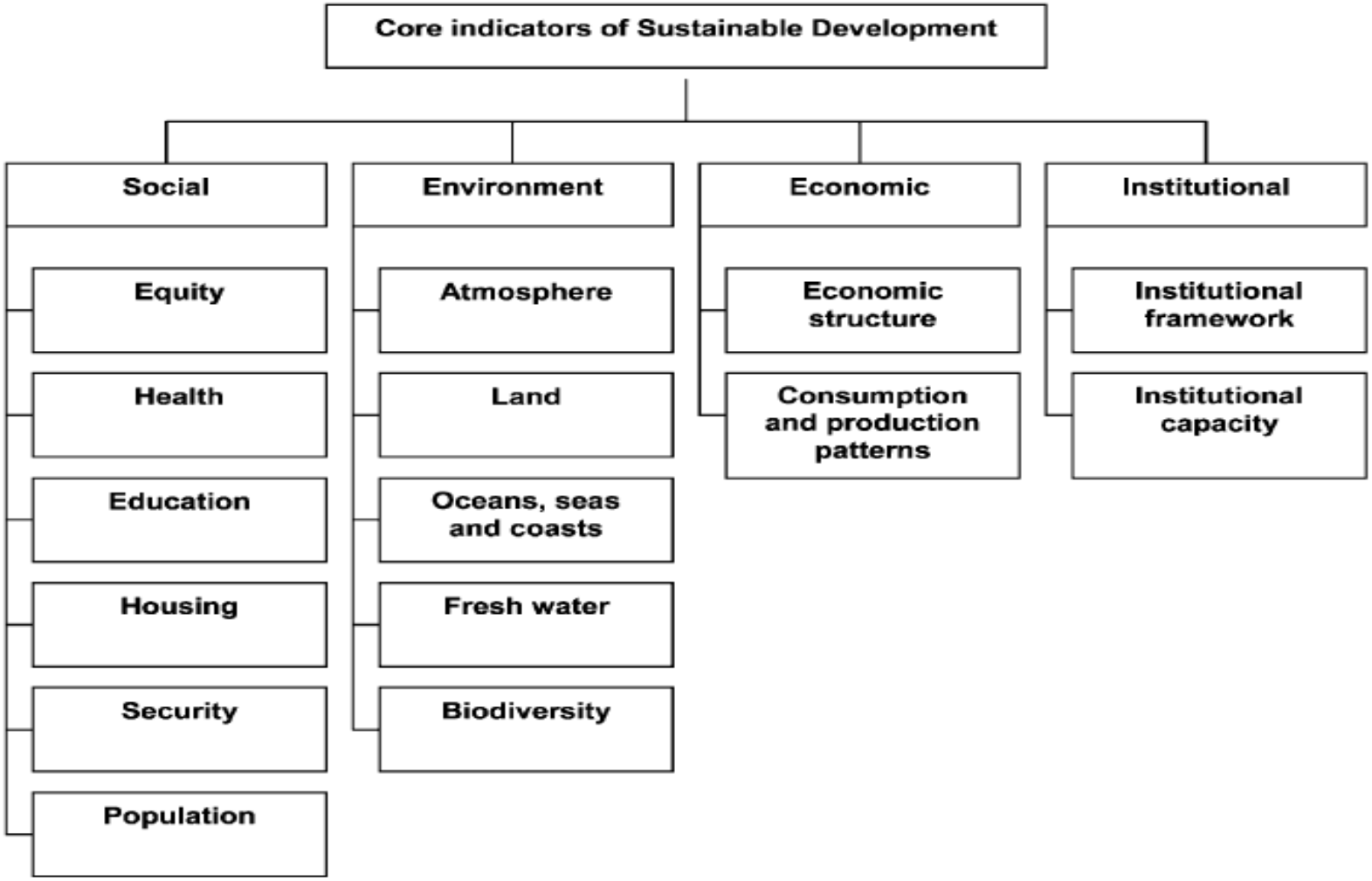


Source: IQNET- APCER Forum 2007

United Nations Commission on Sustainable Development Framework (CSD)

- The United Nations Commission on Sustainable Development (CSD) constructed a sustainability indicator framework for the evaluation of governmental progress towards sustainable development goals.
- A hierarchical framework groups indicators into 38 subthemes and 15 main themes, that are divided between the four aspects of sustainable development

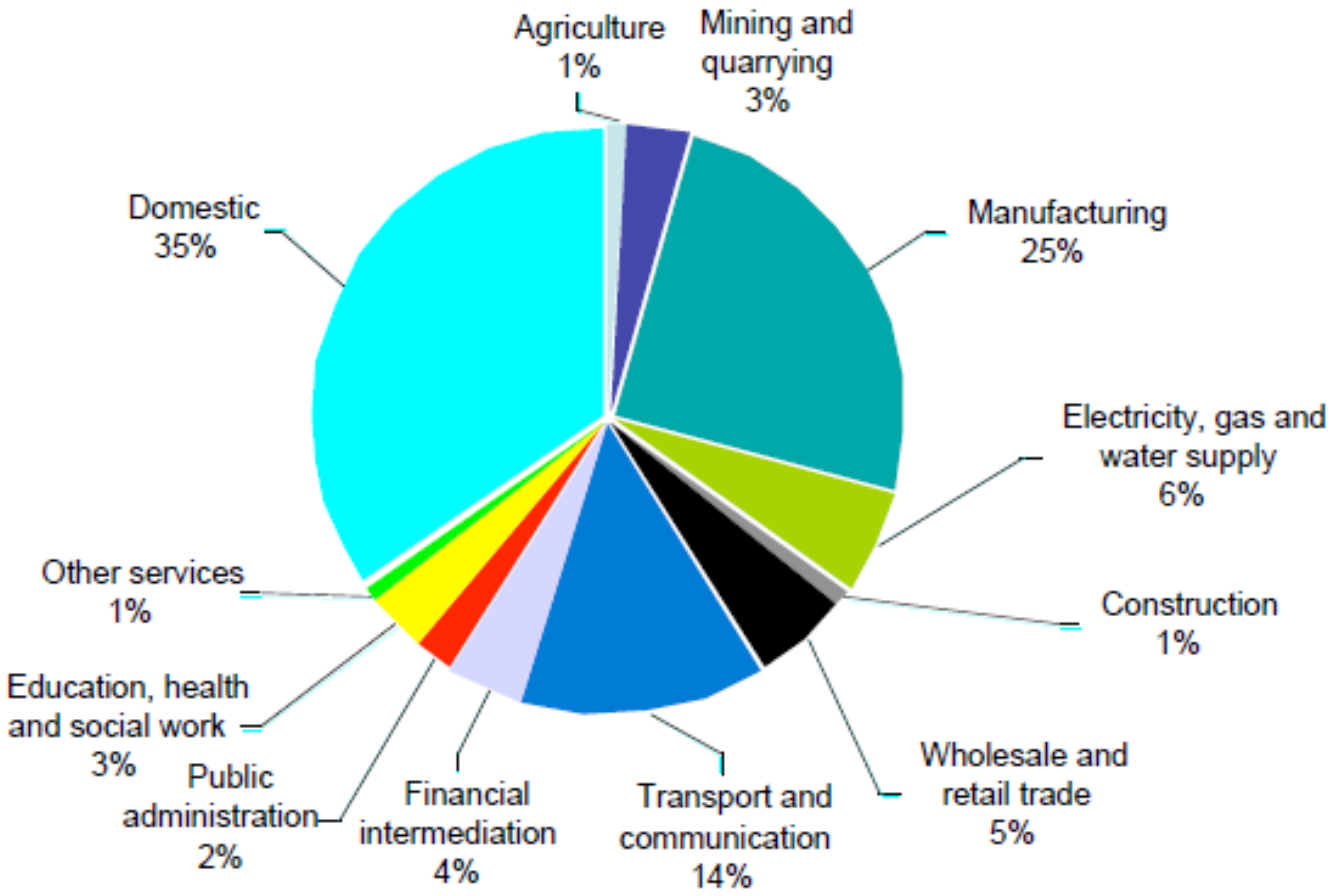
CSD framework



The CSD theme indicator framework

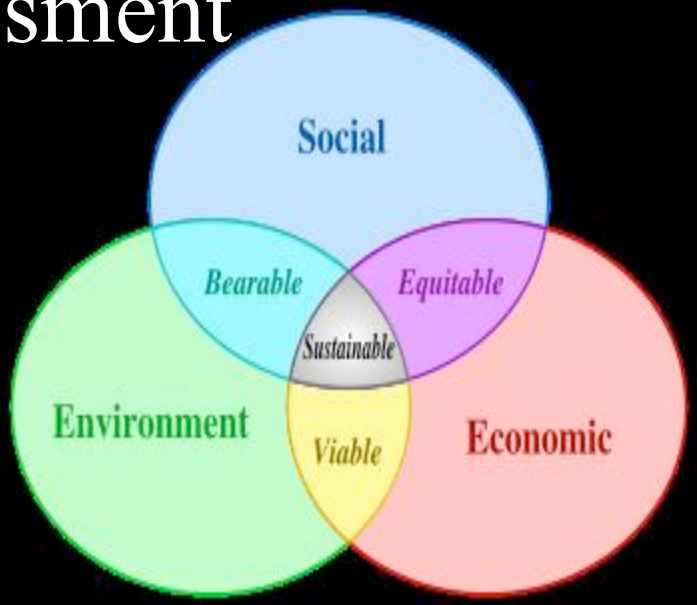
Is that a problem for manufacturing?

UK Energy Consumption 2002



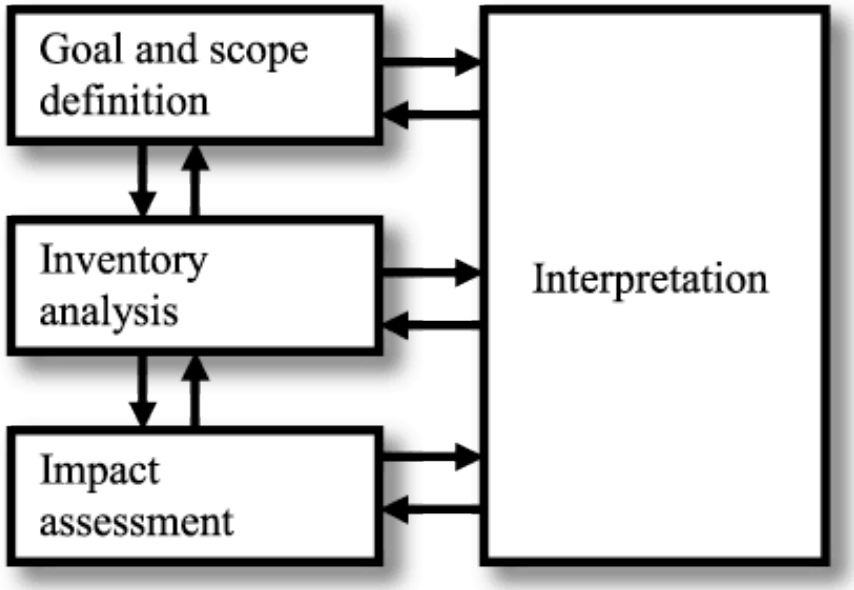
WHY MEASURE SUSTAINABILITY?

Product Life Cycle Assessment

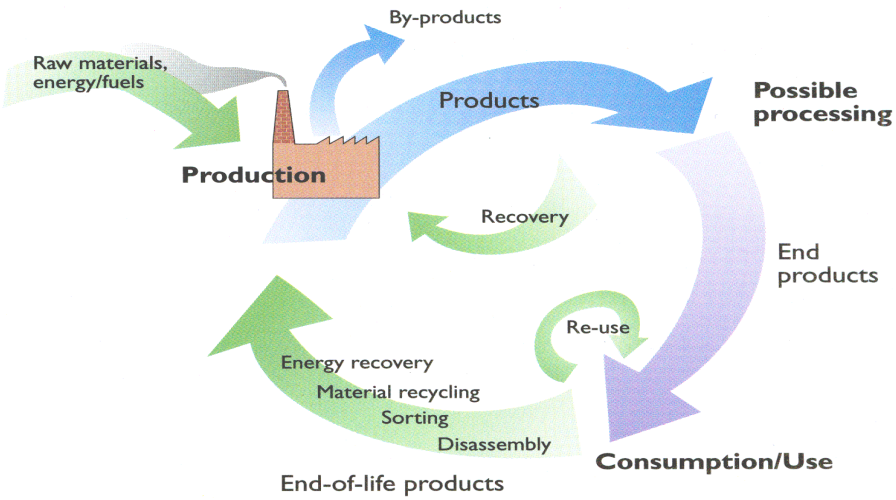


Life Cycle Assessment (LCA)

LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service.



Phases of an LCA (Source: ISO, 1997)



Product Life Cycle (Source: Melanen et al. 2000)

Goal and Scope Definition

The following six basic decision should be made at the beginning of the LCA process to make effective use of time and resources:

1. Define the Goal(s) of the project
2. Determine what type of information is needed to inform the decision-makers
3. Determine the required specificity
4. Determine how the data should be organized and the results displayed
5. Define the scope of the study
6. Determine the ground rules for performing the work

Inventory Analysis

The four steps of a life cycle inventory:

1. Develop a flow diagram of the process being evaluated
2. Develop a data collection plan
3. Collect data
4. Evaluate and report results

Economic Input/Output approach:

It offers an alternative way to create life cycle inventory. The input/output model divides an entire economy into distinct sectors and represents them in table, or matrix, form so that each sector is represented by one row and one column. The matrix represents sales from one sector to another.

In order to create life cycle inventory, the economic output for each sector is first calculated, then the environmental outputs are calculated by multiplying the economic output at each stage by the environmental impact per dollar of output

IEEE P1680 Family of Standards for Environmental Assessment of Electronic Products

- This Family of Standards provides clear and consistent performance criteria for the design of electronic products thereby providing an opportunity to secure market recognition for efforts to reduce the environmental impact of electronic products.
  - *IEEE P1680 Standard for Environmental Assessment of Electronic Products – The Umbrella Standard for the 1680 Family of Standards*
  - *IEEE P1680.1 Standard for Environmental Assessment of Personal Computer Products including Laptop Computers, Desktop Personal Computers, and Personal Computer Monitors*
  - *IEEE P1680.2 Standard for Environmental Assessment of Imaging Equipment*
  - *IEEE P1680.3 Standard for Environmental Assessment of Televisions*

IEEE P1680

IEEE P1680 contains 23 required criteria and 28 optional criteria. To qualify for registration as an EPEAT product, the product must conform to all the required criteria.

Table: IEEE P1680 criteria (top-level)

4.1 Reduction/elimination of environmentally sensitive materials
4.2 Materials selection
4.3 Design for end of life
4.4 Product longevity/life cycle extension
4.5 Energy conservation
4.6 End of life management
4.7 Corporate performance
4.8 Packaging

EPEAT

BRONZE

Meets all 23 required criteria

SILVER

Meets all 23 required criteria plus at least 50% of the optional criteria

GOLD

Meets all 23 required criteria plus at least 75% of the optional criteria

Limitations of Current LCA

Up to now, LCA has obtained a widespread use for decision support, but LCA traditionally only considers environmental impacts and to some extent working environment impacts. Therefore, recommendations based on LCA fail to address possible trade-offs between environmental protection and both social and economic concerns in the product life cycle. This raises questions about LCA's ability to support actual decision-making in companies, which aim for sustainability, and it creates an incentive for developing LCA methodology to include these other dimensions of sustainability.

Table: Areas of protection and underlying societal values in Environmental LCA

Areas of Protection	Societal values
Human health	Intrinsic value of human life, economic value
Natural environment	Intrinsic value of nature (ecosystems, species), economic value of life support functions
Natural resources	Economic and intrinsic values
Man-made environment	Cultural, economic, and intrinsic values

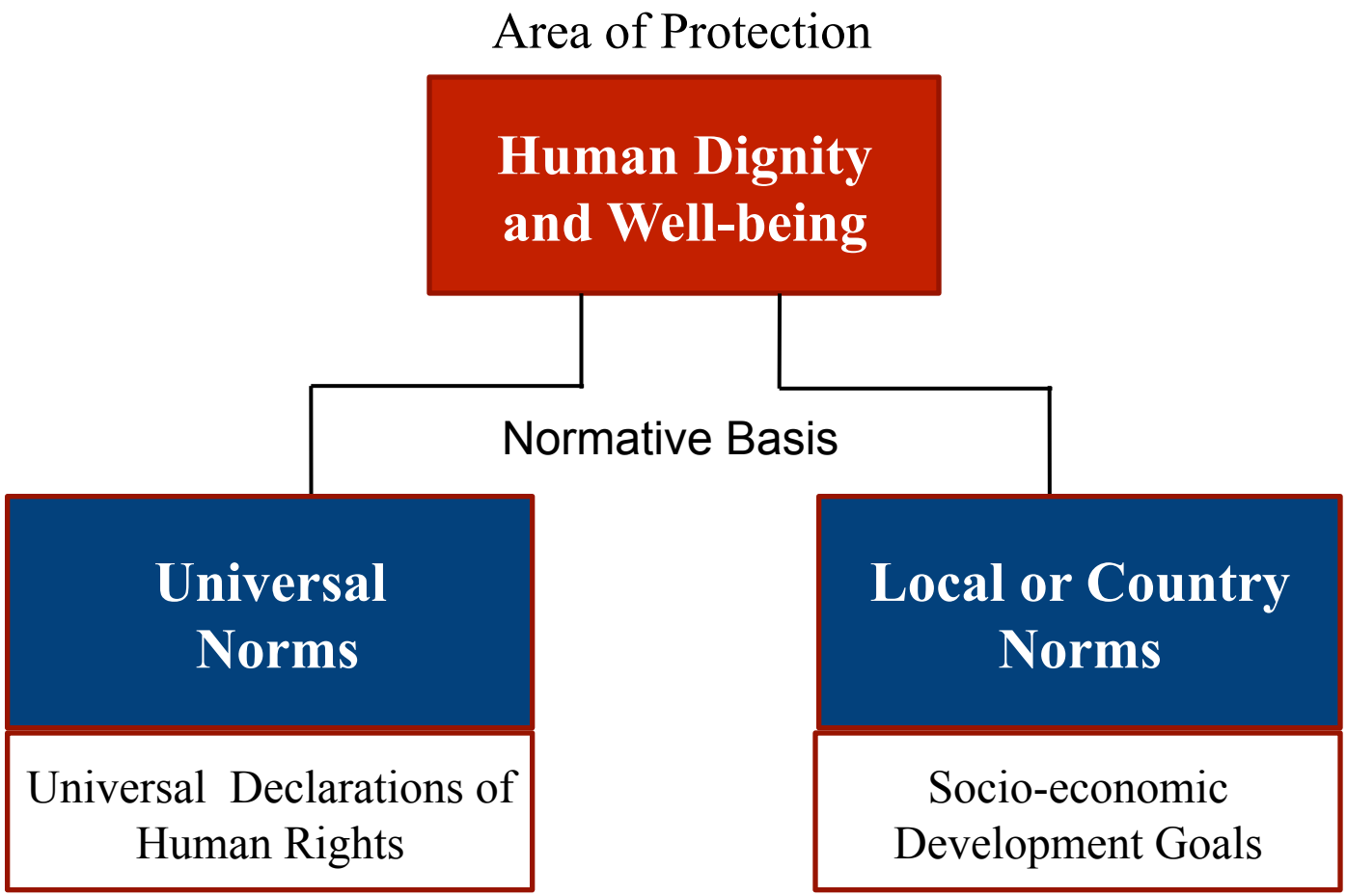
Social LCA

Three important prerequisites can be identified for a good and decent life

- *Human health*: to live a healthy and naturally long life
- *Human dignity*: to live a decent life and enjoy respect and social membership
- *Basic needs fulfillment*: to have access to food, water, clothes, medical care, etc.

These prerequisites are interrelated as human health and, in many cases, human dignity, are promoted by, and even dependent on, fulfillment of basic needs. In keeping with this, a new area of protection is suggested: **Human Dignity** and **Well-being**.

Social LCA


Area of Protection
Human Dignity and Well-being
Normative Basis
Universal Norms
Universal Declarations of Human Rights
Local or Country Norms
Socio-economic Development Goals

Universal Norms

- The universal Declaration of Human Rights (UDHR)
  - *The first document in history considered to have universal validity*
  - *Expresses the fundamental human rights as a way to protect and promote human dignity and well-being*
- The International Labor Organization (ILD) Conventions
  - *The ILO has both inspired, and been inspired by, the UDHR*
  - *The interpretation of human rights in a labor market context*
- Tripartite Declaration of Principles concerning Multinational enterprises and Social Policy
  - *Give guidance based on the ILO Conventions and Recommendations*
  - *Emphasizes the role of companies in regard to promotion of economic and social welfare in developing countries*

Local or Country Relevant Norms

- It is necessary to consider the socio-economic and political problems on a country or regional basis to determine some of the relevant issues for Social LCA, the local or country relevant norms
- It is recommended to start from the National or regional Human Development Reports
  - *Corruption and bribery, payment of income tax, prevention of illiteracy and contribution to health care, e.g. in areas where HIV/AIDs causes big societal problems, are all examples of important topics which cannot be ignored when doing business certain places in the world*

Social indicators

Product Responsibility— Performance Indicators

Aspect: Customer Health and Safety

CORE

PR1 Life cycle stages in which health and safety impacts of products and services are assessed for improvement, and percentage of significant products and services categories subject to such procedures.

ADD

PR2 Total number of incidents of non-compliance with regulations and voluntary codes concerning health and safety impacts of products and services, by type of outcomes.

Aspect: Product and Service Labeling

CORE

PR3 Type of product and service information required by procedures, and percentage of significant products and services subject to such information requirements.

ADD

PR4 Total number of incidents of non-compliance with regulations and voluntary codes concerning product and service information and labeling, by type of outcomes.

Aspect: Marketing Communications

CORE

PR6 Programs for adherence to laws, standards, and voluntary codes related to marketing communications, including advertising, promotion, and sponsorship.

ADD

PR7 Total number of incidents of non-compliance with regulations and voluntary codes concerning marketing communications, including advertising, promotion, and sponsorship, by type of outcomes.

Aspect: Customer Privacy

ADD

PR8 Total number of substantiated complaints regarding breaches of customer privacy and losses of customer data.

Aspect: Compliance

CORE

PR9 Monetary value of significant fines for non-compliance with laws and regulations concerning the provision and use of products and services

Social indicators

Human Rights — Performance Indicators

Aspect: Investment and Procurement Practices

CORE **HR1** Percentage and total number of significant investment agreements that include human rights clauses or that have undergone human rights screening.

CORE **HR2** Percentage of significant suppliers and contractors that have undergone screening on human rights and actions taken.

ADD **HR3** Total hours of employee training on policies and procedures concerning aspects of human rights that are relevant to operations, including the percentage of employees trained.

Aspect: Non-discrimination

CORE **HR4** Total number of incidents of discrimination and actions taken.

Aspect: Forced and Compulsory Labor

CORE **HR7** Operations identified as having significant risk for incidents of forced or compulsory labor, and measures taken to contribute to the elimination of forced or compulsory labor.

Aspect: Security Practices

ADD **HR8** Percentage of security personnel trained in the organization's policies or procedures concerning aspects of human rights that are relevant to operations.

Aspect: Indigenous Rights

ADD **HR9** Total number of incidents of violations involving rights of indigenous people and actions taken.

Society — Performance Indicators

Aspect: Community

CORE **S01** Nature, scope, and effectiveness of any programs and practices that assess and manage the impacts of operations on communities, including entering, operating, and exiting.

Aspect: Corruption

CORE **S02** Percentage and total number of business units analyzed for risks related to corruption.

CORE **S03** Percentage of employees trained in organization's anti-corruption policies and procedures.

CORE **S04** Actions taken in response to incidents of corruption.

Aspect: Public Policy

CORE **S05** Public policy positions and participation in public policy development and lobbying.

ADD **S06** Total value of financial and in-kind contributions to political parties, politicians, and related institutions by country.

Aspect: Anti-Competitive Behavior

ADD **S07** Total number of legal actions for anti-competitive behavior, anti-trust, and monopoly practices and their outcomes.

Aspect: Compliance

CORE **S08** Monetary value of significant fines and total number of non-monetary sanctions for non-compliance with laws and regulations.

Social LCA

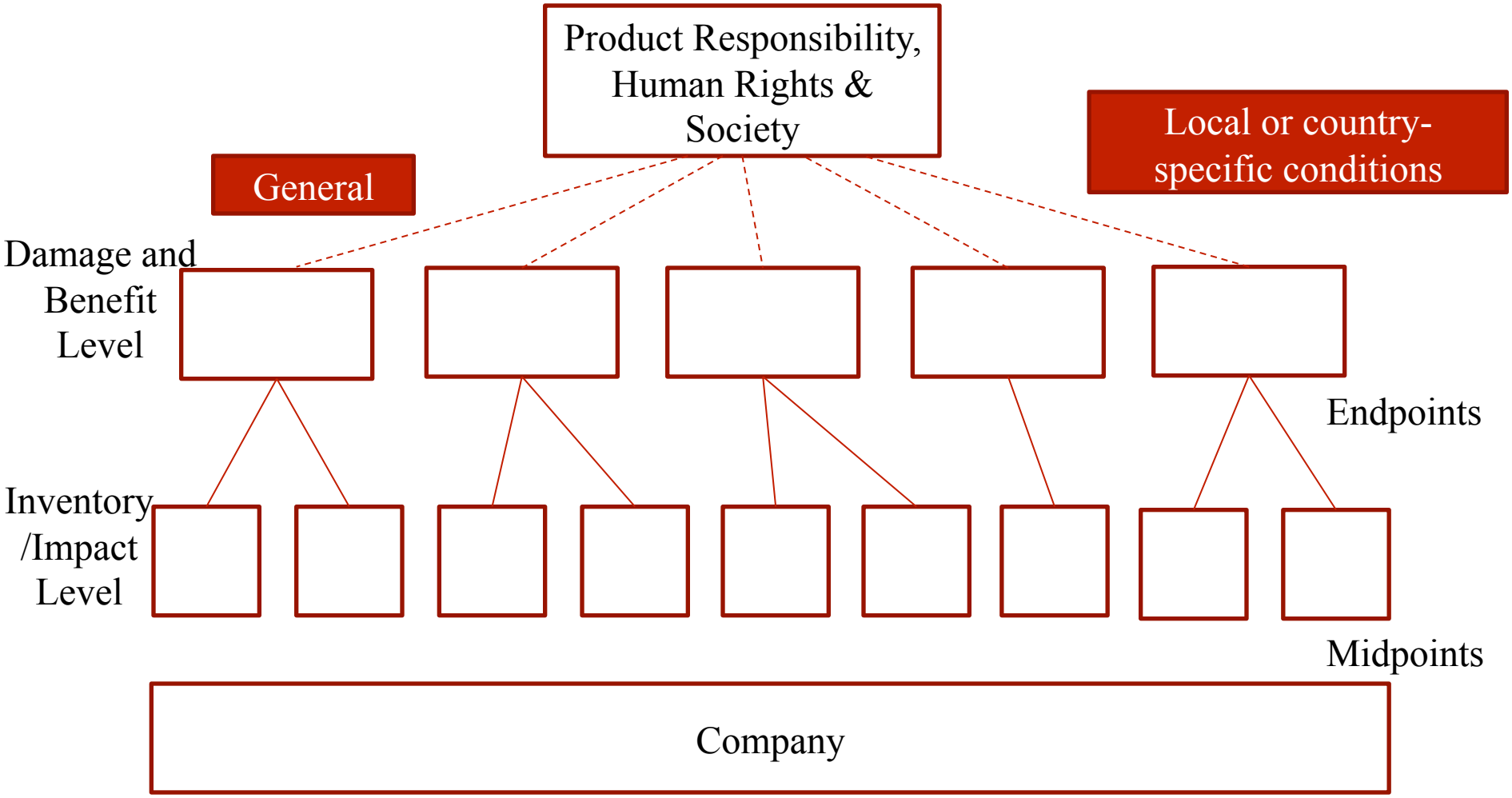


Figure: The impact model of the Social LCIA framework

Economic LCA

Tool/Method	LCA	LCC
Purpose	Compare relative environmental performance of alternative product systems for meeting the same end-use function, from a broad, societal perspective	Determine cost-effective of alternative investments and business decisions, from the perspective of an economic decision maker such as a manufacturing firm or a consumer
Activities included	All processes causally connected to the physical life cycle of the product	Activities causing direct costs or benefits to the decision maker during the economic life of the investment, as a result of the investment
Flows considered	Pollutants, resources, and inter-process flows of materials and energy	Cost and benefit monetary flows directly impacting decision maker
Units for tracking flows	Primarily mass and energy; occasionally volume, other physical unites	Monetary units (e.g., dollars, euro, etc.)
Time treatment and scope	The timing of processes and their release or consumption flows is traditionally ignored; impact assessment may address a fixed time window of impacts	Timing is critical. Present valuing (discounting) of costs and benefits. Specific time horizon scope is adopted, and any costs or benefits occurring outside that scope are

Sustainability Indices

What are sustainability indices and why are they needed?

– An "***indicator***" is a variable which describes one characteristic of the state of a system, usually through observed or estimated data.

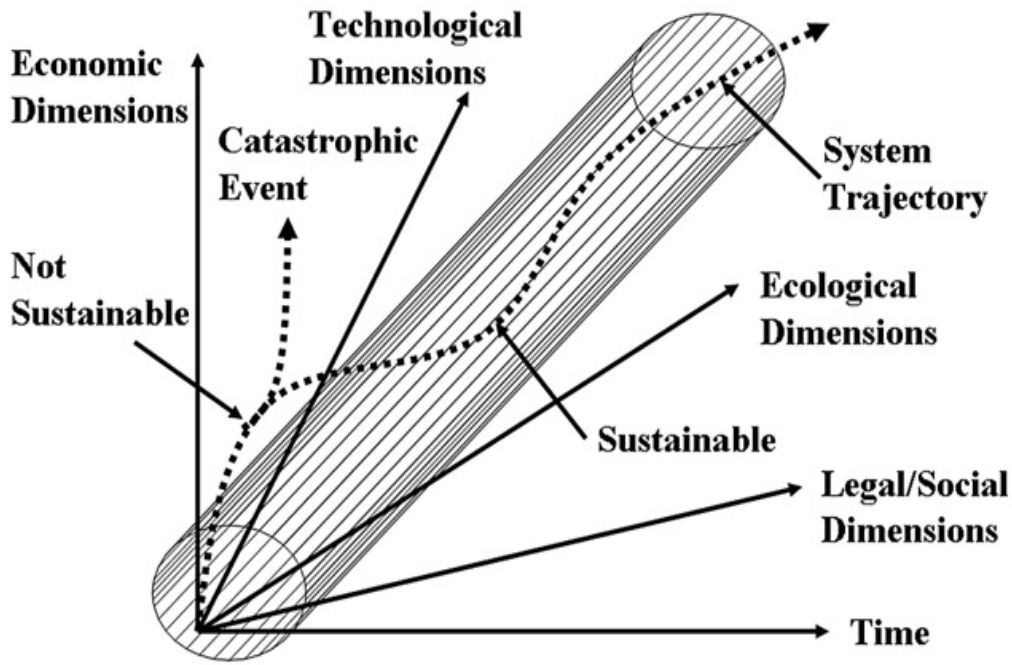
– An "***index***" is a quantitative aggregation of many indicators and can provide a simplified coherent, multidimensional view of a system.

Table: Comparison of index characteristics

Index name	Aggregation Method	# of indicators	Distance to policy target
Wellbeing	Average	36	Yes
Environmental Sustainability	Average	76	No
Natural Capital	Sum	7	Yes
Satellite-based Sustainability	Ratio	2	No
Sparse PCA	Regression	-	No
SPTIPAT	System variability	11	No
Fisher Information	Accounting	-	possible
Genuine Savings	Accounting	-	Yest
Sustainable National Income	Accounting	-	Yes
Exergy Analysis	Accounting	-	Yes
Ecological Footprint	Accounting	-	Yes

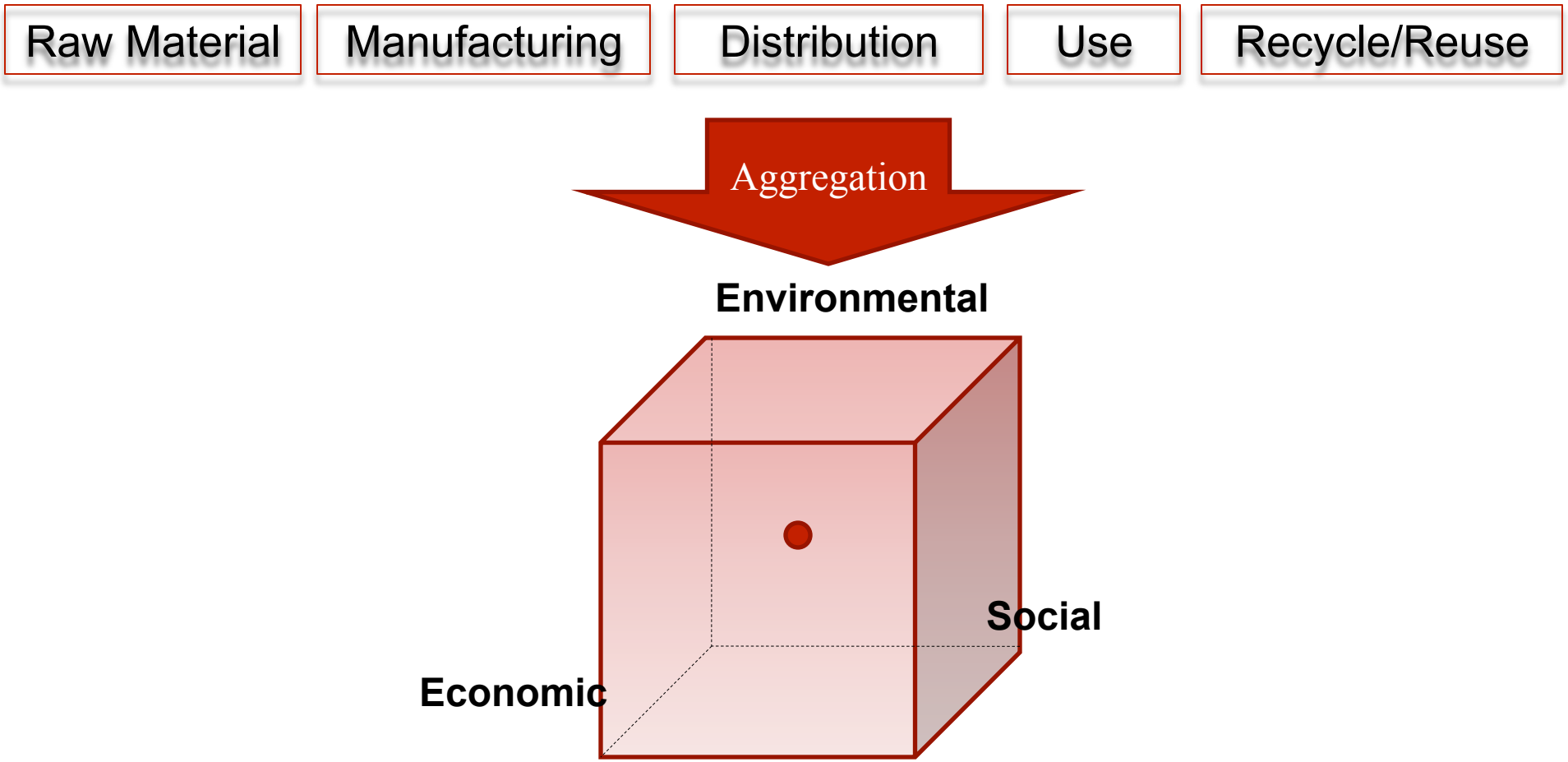
Dimensions of sustainability

The trajectory of a system, and the position of the system with respect to multidimensional sustainable boundaries, are both necessary to determine system sustainability. A system which is unsustainable in one dimension is not generally sustainable. Multiple indicators are measured for each dimension, and aggregated into an index which identifies the overall position and trajectory of the system.



Source: A.L. Mayer /Environment International 34 (2008) 277-291

Target: A unified sustainability measure



Bottom-up: sums, averages, and ratios

One of the most straightforward and common aggregation methods is to simply add or average the data

Examples: Wellbeing Index, Environmental Sustainability Index, Natural Capital Index

Top-down: carrying capacity/accounting

Carrying capacity is a concept which originated in ecology, based on thermodynamically set limits to resource stocks and flows. While quite large, the flow of solar energy reaching the Earth is nevertheless fixed, as is the mass of the Earth. Since all resources are a combination of mass and energy, the total amount of resources available to humans and all other species is fixed.

Examples: Green GDP indices

Principal Component Analysis (PCA)

- Principal Component Analysis (PCA) is a popular statistical data reduction technique. PCA be used to aggregate sustainability indicators at a variety of scales. (Sands and Podmore, 2000; Morse and Fraser, 2005)

- The advantages of using PCA are:
  - *It is one of the leased biased approaches to the aggregation of sustainability indicators, since indicators are grouped by their statistical behavior and not by preconceived notions of their influence.*
  - *It can usually aggregate an unlimited number of indicators, irrespective of the measurement units*
  - *It can avoid overfilling and effectively reduce dimensionality*
  - *It is a fast and timely methodology which has a wide applications: face recognition and image compression*

Principal components analysis (PCA)

Case study: Calculating Environmental Sustainability Index (ESI) for agricultural systems

The matrix of sustainability sub-indices for a case study can be written as follows, where the *i*th row represents one of the 17 crop management scenarios and the *j*th column represents one of the 15 sub-indices.

$$\begin{bmatrix} \mathbf{SI}_{1,1} & \mathbf{SI}_{1,2} & \dots & \mathbf{SI}_{1,15} \\ \mathbf{SI}_{2,1} & \mathbf{SI}_{2,2} & \dots & \mathbf{SI}_{2,15} \\ \vdots & \vdots & \vdots & \vdots \\ \mathbf{SI}_{17,1} & \mathbf{SI}_{17,2} & \dots & \mathbf{SI}_{17,15} \end{bmatrix}$$

When PCA is applied to the portfolio of crop management systems, the sustainability sub-indices were assigned individual weights or loadings on each principal component (PC). The weighting vectors are referred to as eigenvectors in PCA.

Principal components analysis (PCA)

The ESI can be expressed in terms of these eigenvectors as follows:

$$\mathrm{ESI} = \sum_{j=1}^{\mathrm{nc}} \mathrm{PC}_j$$

$$\mathrm{PC}_j = \sum_{i=1}^{15} \mathrm{SI}_i x \mathrm{W}_{i,j}$$

Where nc is the number of principal components retained, and W*i,j* is the eigenvector associated with the *j*th principal component.

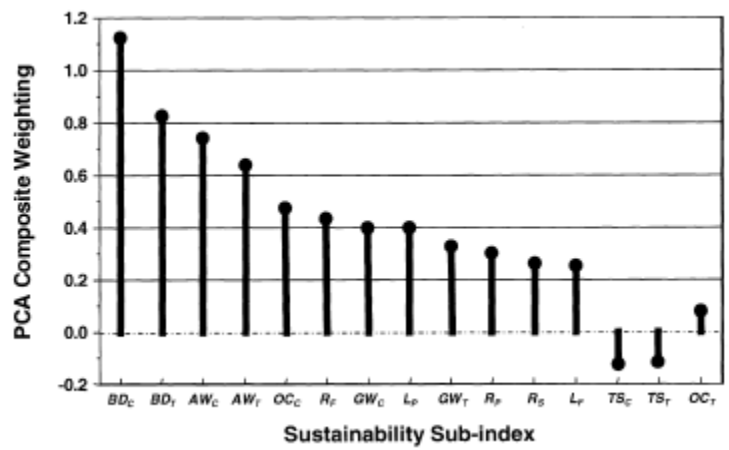


Figure: *Component weights assigned to the 15 sustainability sub-indices through PCA for a 300-year computational time frame*

Future Research

- Survey and questionnaire design for social and economic sustainability
- Data analysis and aggregation through PCA
- Development of sustainability indices

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