National Academies of Sciences, Engineering, and Medicine's Workshop - Transition toward Sustainability after 15 Years: Where Do We Stand in Advancing the Scientific Foundation

Welcome to Mars

A Toolbox for Sustainable Science and Engineering

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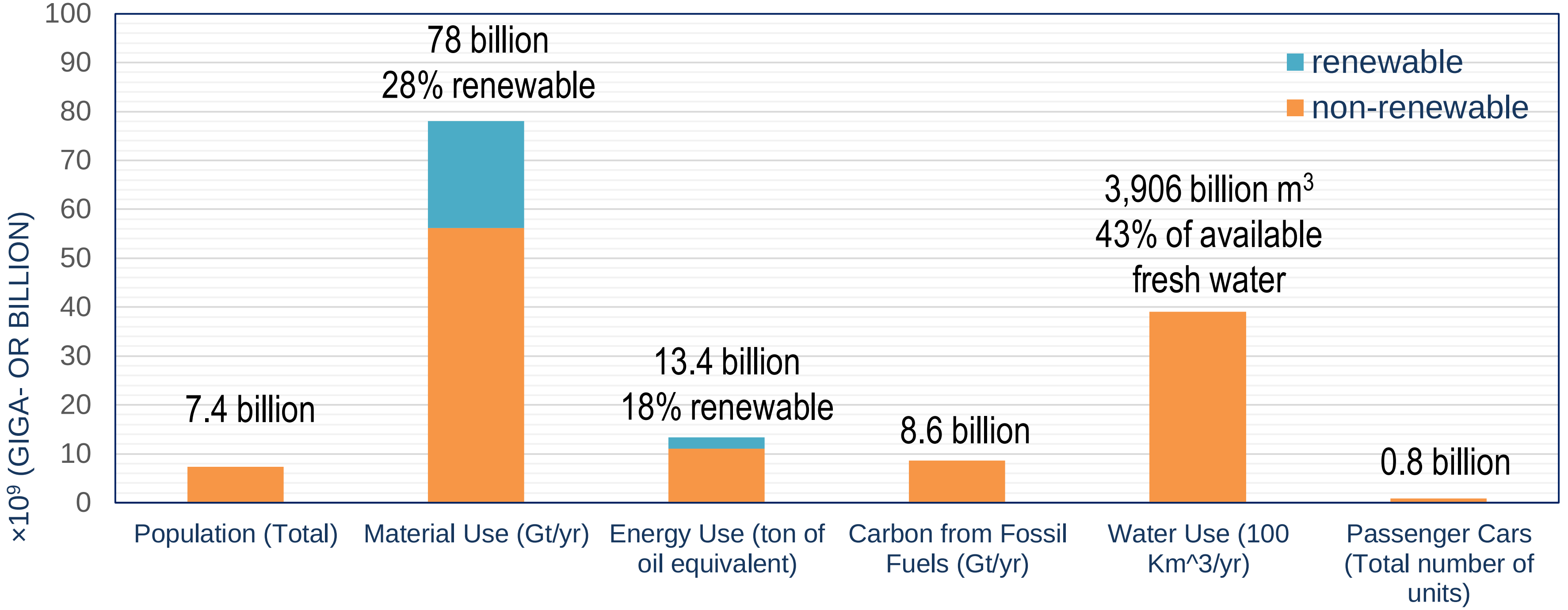
Sustainable Systems

- We need to recreate the anthroposphere to exist within the means of nature.
- First Premise: Generate waste that nature can assimilate without overwhelming natural cycles.
    - Need to look at fate of toxics, Nitrogen, Phosphorus, Water, and Carbon cycles and more.
- Second Premise: Use renewable resources/ recycle materials in commerce

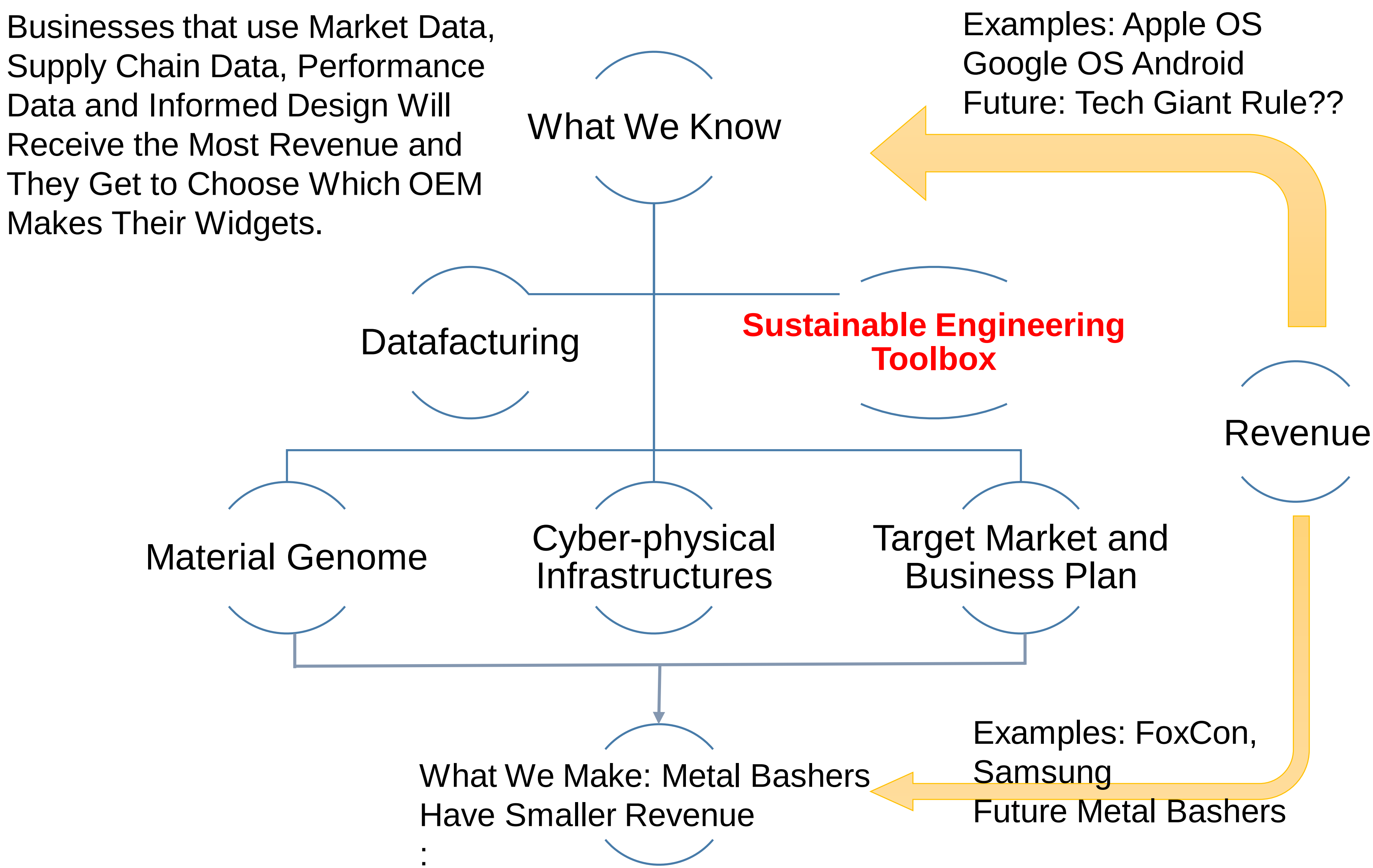
Gigaton Problems Need Gigaton Solutions

- With ***1 billion people*** using ***70 Gt of materials***, ***13.4 Gtoe of energy***, ***3,906 Gm³ of water*** and emitting ***8.6 Gt of Carbon*** per year globally to produce ***71,000 G$ GDP***
- ***Need technologies that scale!!***
- From an egalitarian point of view, we should expect this to increase by a factor of 9 for 9 billion people in 2050, if every one has the same life style and uses today's technologies.



Note: Material use includes food

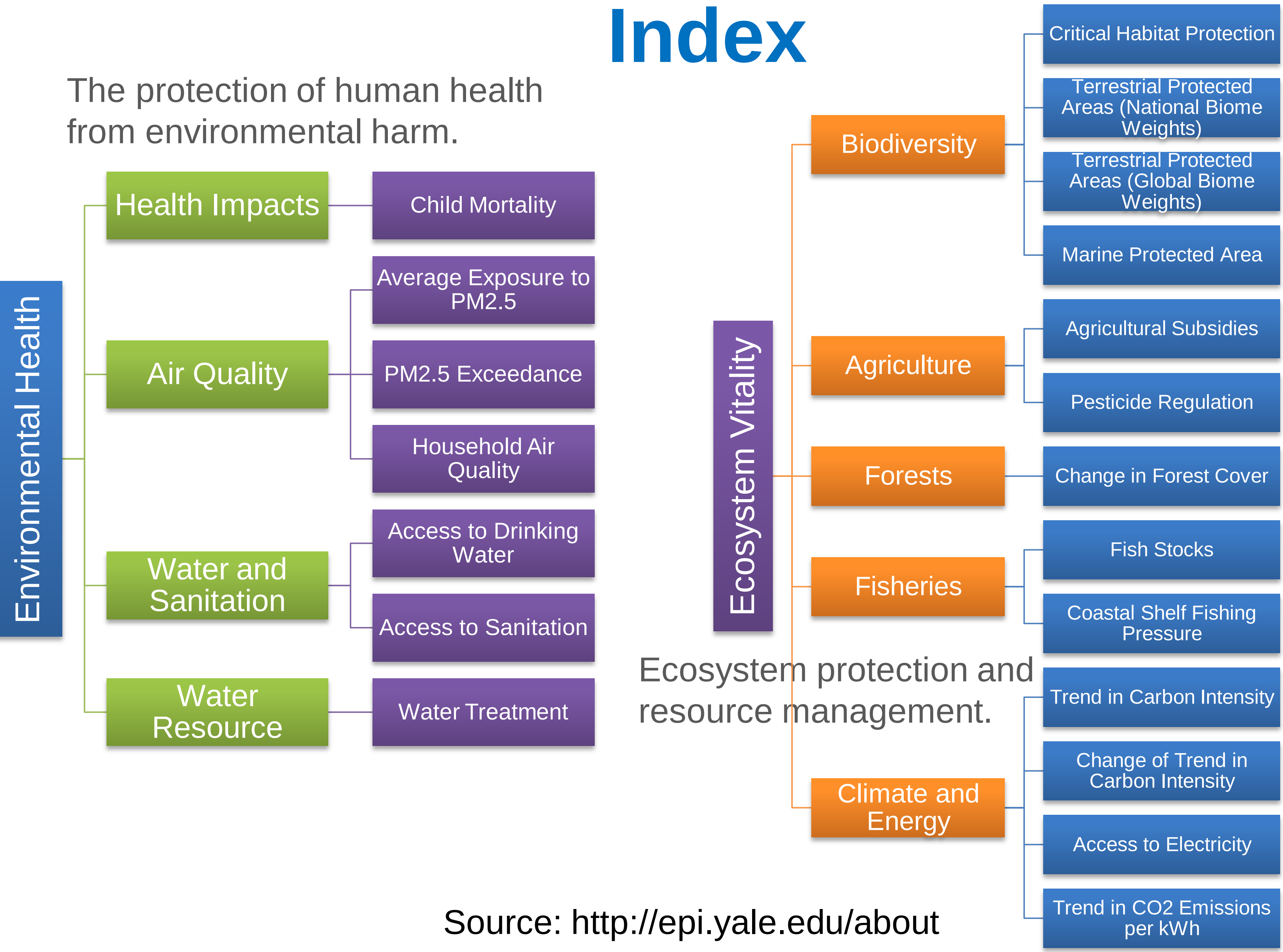
Manufacturing 4.0: What We Know is Worth More What We Make and a Great Opportunity for Sustainable Engineering



Sustainability Indicators and Metrics

- Ecological Sustainability Indicators
  - Ecological Footprint
    - The biologically productive and mutually exclusive areas necessary to continuously provide for people's resource supplies and the adsorption of their wastes.
  - Carbon Footprint
  - Water Footprint
    - Green water footprint: volume of rainwater evaporated or incorporated into product
    - Blue water footprint: volume of surface or groundwater evaporated, incorporated into product or returned to other catchment or the sea
    - Grey water footprint: volume of polluted water
- Social Sustainability Indicators
  - Genuine Progress Indicator (GPI)
  - Happy Planet Index (HPI)
    - The degree to which long and happy lives (life satisfaction and life expectancy are multiplied together to calculate happy life years) are achieved per unit of environmental impact
  - Human Development Index (HDI)
    - The combination of life expectancy, educational attainment and income
- Environmental Sustainability Index (ESI)

Environmental Sustainability Index



Source: http://epi.yale.edu/about

Quantitative Key Performance Indicators (KPI) of Tianjin Eco-City, China

Good Natural Environment

- Ambient Air Quality
- Quality of water bodies within the Eco-city
- Quality of Water from Taps
- Noise Pollution Levels
- Carbon Emission Per Unit GDP
- Net Loss of Natural Wetlands

Healthy Balance in the Man–made Environment

- Proportion of Green Buildings
- Native Vegetation Index
- Per Capita Public Green Space

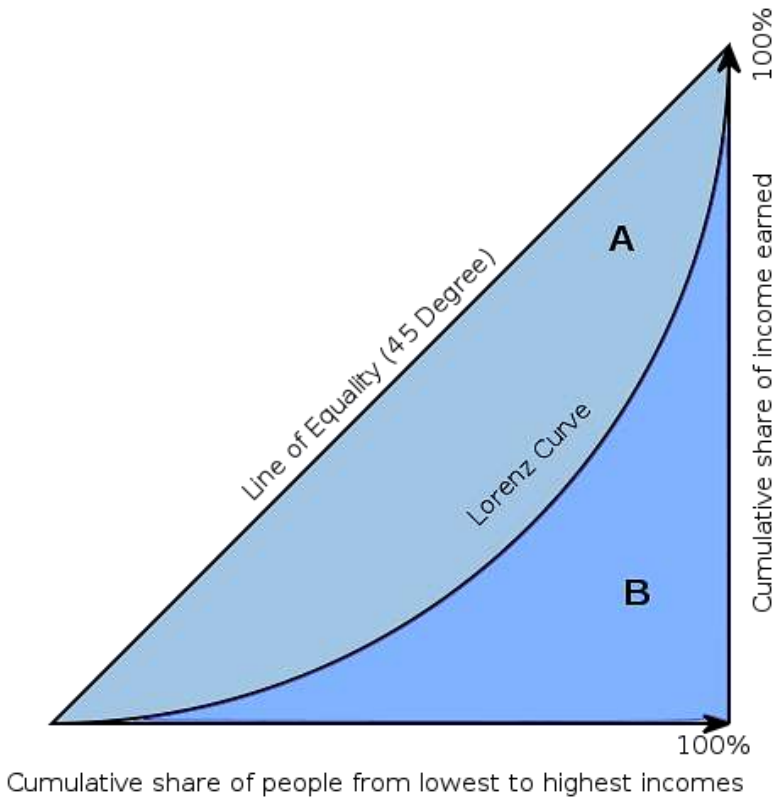
Good Lifestyle Habits

- Per Capita Daily Water Consumption
- Per Capita Daily Domestic Waste Generation
- Proportion of Green Trips
- Overall Recycling Rate
- Access to Free Recreational and Sports Amenities
- Waste Treatment
- Barrier-Free Accessibility
- Services Network Coverage
- Proportion of Affordable Public Housing

Developing a Dynamic and Efficient Economy

- Usage of Renewable Energy
- Usage of Water from Non-Traditional Sources
- Proportion of R&D Scientists and Engineers in the Eco-city Workforce
- Employment-Housing Equilibrium Index

Gini Coefficient



- The Gini coefficient measures the inequality among values of a frequency distribution (for example levels of income).
- A Gini coefficient of zero expresses perfect equality where all values are the same (for example, where everyone has an exactly equal income).
- A Gini coefficient of one (100 on the percentile scale) expresses maximal inequality among values (for example where only one person has all the income).
- The global income inequality Gini coefficient in 2005, for all human beings taken together, has been estimated to be between 0.61 and 0.68 by various sources.

The Gini index is defined as a ratio of the areas on the Lorenz curve diagram. If the area between the line of perfect equality and the Lorenz curve is *A*, and the area under the Lorenz curve is *B*, then the Gini index is $A / (A + B)$. Since $A + B = 0.5$, the Gini index, $G = 2A = 1 - 2B$.

Palma Ratio

- **Palma ratio divides the income share of the top 10% of the population by the income share of the bottom 40%.**
- **In countries with relative income equality this ratio is around one indicating that people in the top 10% on average earn four times the income of people in the bottom 40%.**
- In more unequal societies, the ratio is higher (e.g., 7 in South Africa and 4.8 in Bolivia).
- The strength of the Palma ratio is that it directly communicates the income distribution between poor and rich.
- However, it evens out the internal differences in the two groups.

Source: Cobham and Sumner, 2013, and Index Mundi/the Luxembourg Income Study database.

Indicator of reduced national income inequality: Halving the part of the Palma ratio that exceeds one in 2030 compared to 2010

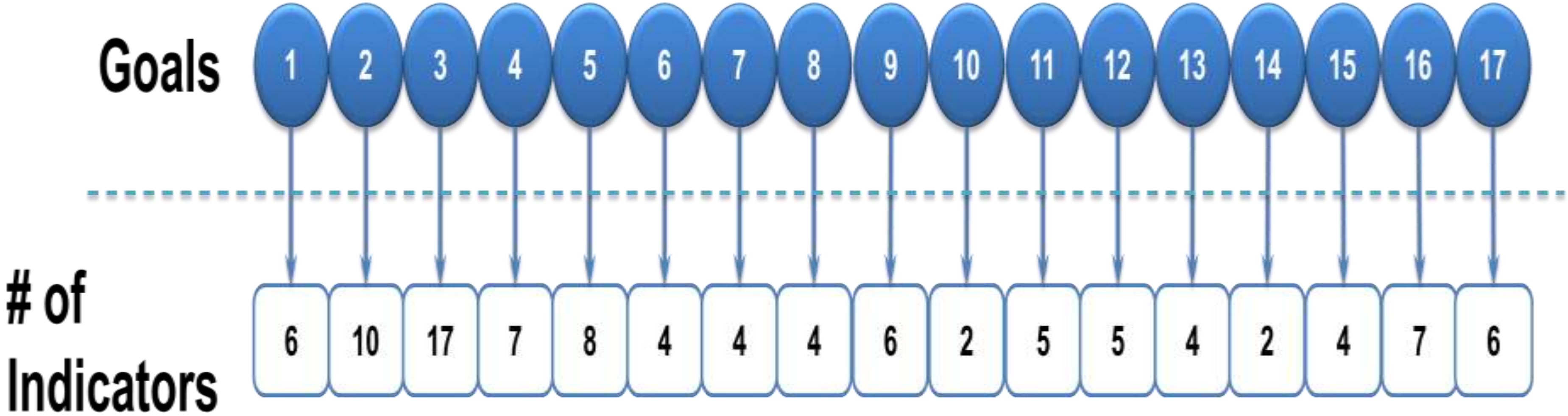
Selected country examples with year of data collection

Country	*Palma ratio 2010 Baseline (x)*	*Palma ratio 2030 Target (y=x-(x-1)/2)*
Bolivia (2008)	4.847	2.924
Brazil (2009)	4.302	2.651
Bulgaria (2007)	0.997	-
Burkina Faso (2009)	1.859	1.430
China (2005)	2.154	1.577
Denmark (1997)	0.922	-
France (1995)	1.267	1.134
Germany (2000)	0.992	-
Ghana (2005)	2.172	1.586
India (2004)	1.355	1.178
Japan (1993)	0.875	-
Malaysia (2009)	2.627	1.814
Netherlands (1999)	1.094	1.047
South Africa (2008)	7.052	4.026
Tanzania (2007)	1.653	1.327
United Kingdom (1999)	1.623	1.312
United States (2000)	1.852	1.426

The data available to calculate the baseline (the Palma ratio 2010) differ much in actuality and quality. Thus, the Palma ratio 2030 target figures are only tentative.

UN Sustainable Development Framework

- The United Nations Sustainable Development Framework consists of 17 Sustainable Development Goals (SDG) and 100 unique Sustainable Development Indicators (SDI).
- Progress in each goal is measures against a set of these indicators.
- Some indicators might be used to measure progress in more than one goal.



Summary of the Toolbox to Improve the Indicators and Metrics

Data & design layer

Systems Monitoring and Communication
- Cyber-physical infrastructure

Systems Intervention
- Systems thinking and design
- Bio-inspired design
- Data enabled design

Citizen Engagement
- Crowdsourcing
  Big Data Analytics

Modeling layer

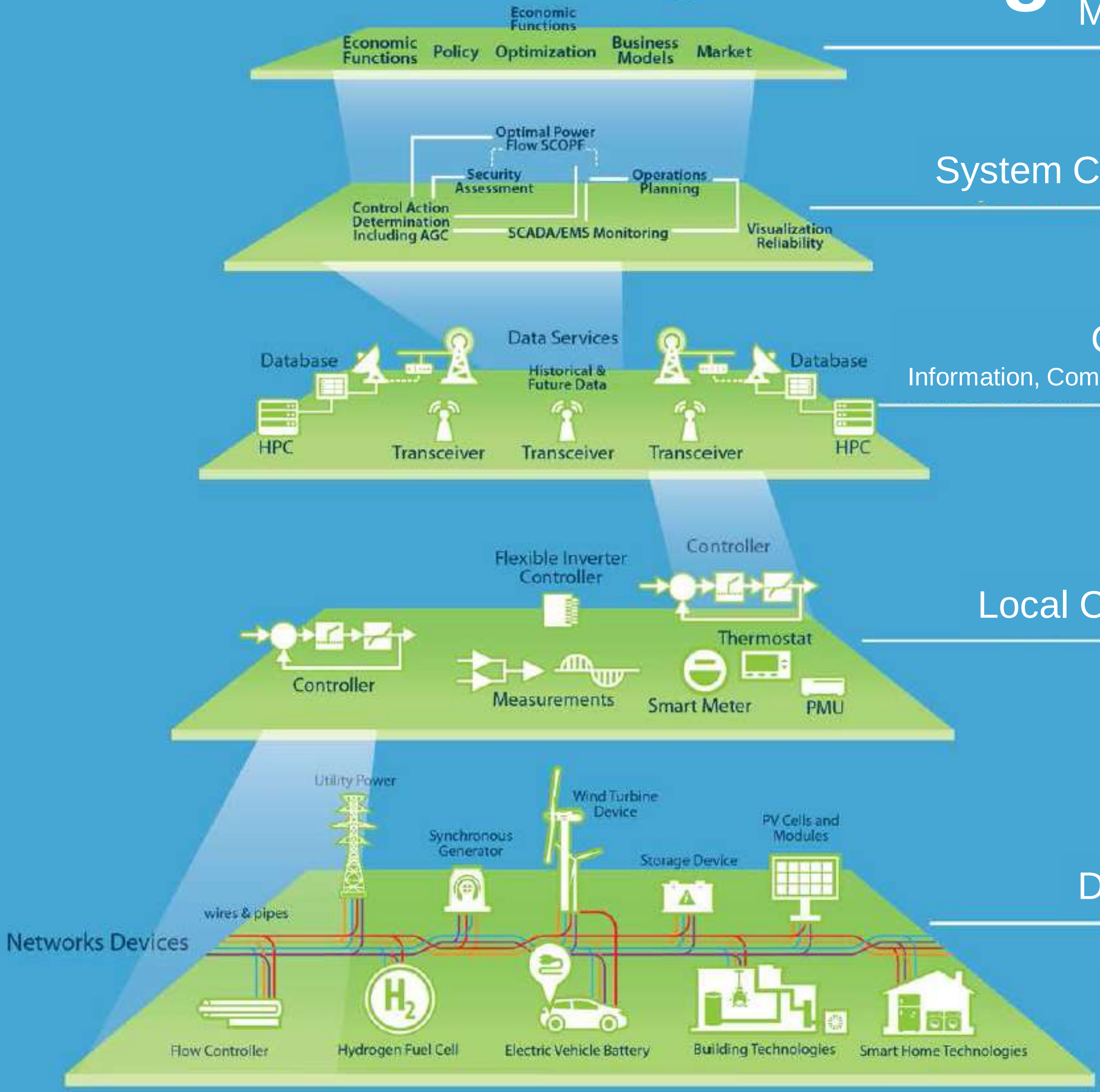
Systems Modeling
- Complexity modeling and management
- Market adoption prediction, policy development

Decision support layer

Systems Analysis
- Life cycle analysis
- Material flow analysis
- Network analysis

Decision Support
- Rating systems
- Target plot
- Optimizing sustainability, resilience and cost

Cyber-physical Infrastructure
Internet of Things



Market Layer

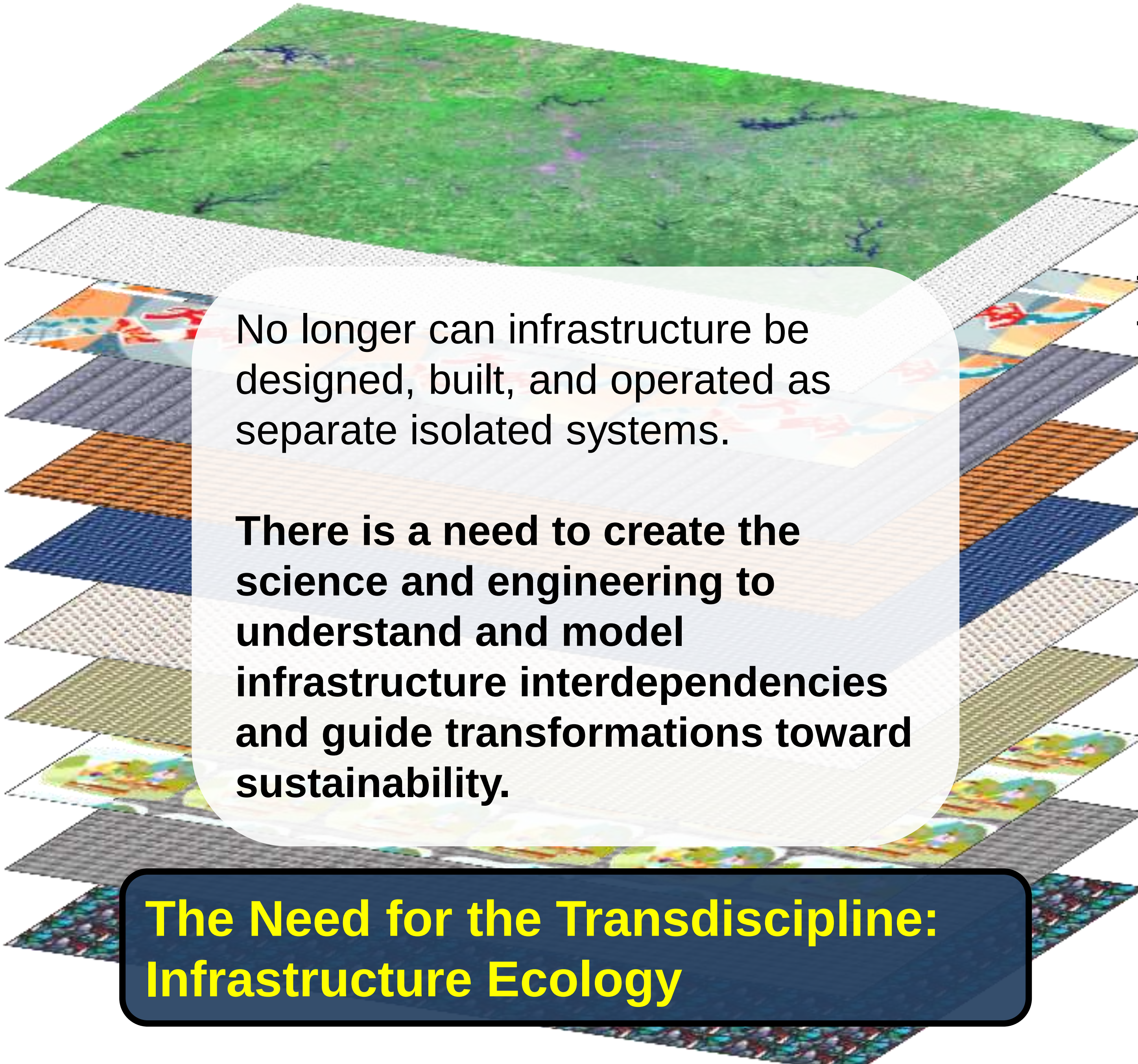
System Control Layer

Cyber Layer
Information, Communication, Computation

Local Control Layer

Device Layer

Credit: Santiago Grijalva, Georiga Tech



No longer can infrastructure be designed, built, and operated as separate isolated systems.

There is a need to create the science and engineering to understand and model infrastructure interdependencies and guide transformations toward sustainability.

The Need for the Transdiscipline: Infrastructure Ecology

Urban Infrastructure

- ✓ **Socioeconomic Properties**
  - Community Values
  - Financial Capital
  - Leadership
- ✓ **Physical**
  - Transportation
  - Energy
  - Water
  - Buildings
  - Parks/Greenways

12 Principles of Infrastructure Ecology

1. Interconnect rather than segregate

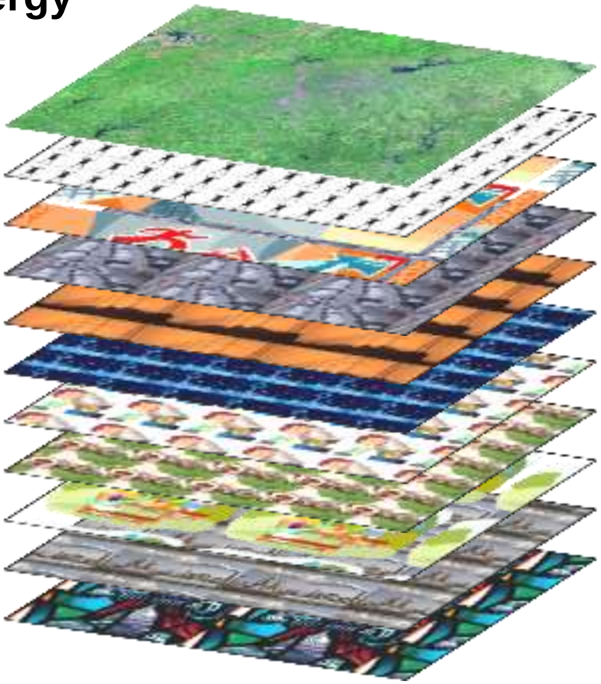
2. Integrate material, energy & water flows

3. Manage inherent complexity

4. Account for systems dynamics

5. Decentralize to increase response diversity and modularity

6. Maximize sustainability and resilience of material & energy investment



7. Find synergies between engineered & ecological systems

8. Take stakeholder preferences into account

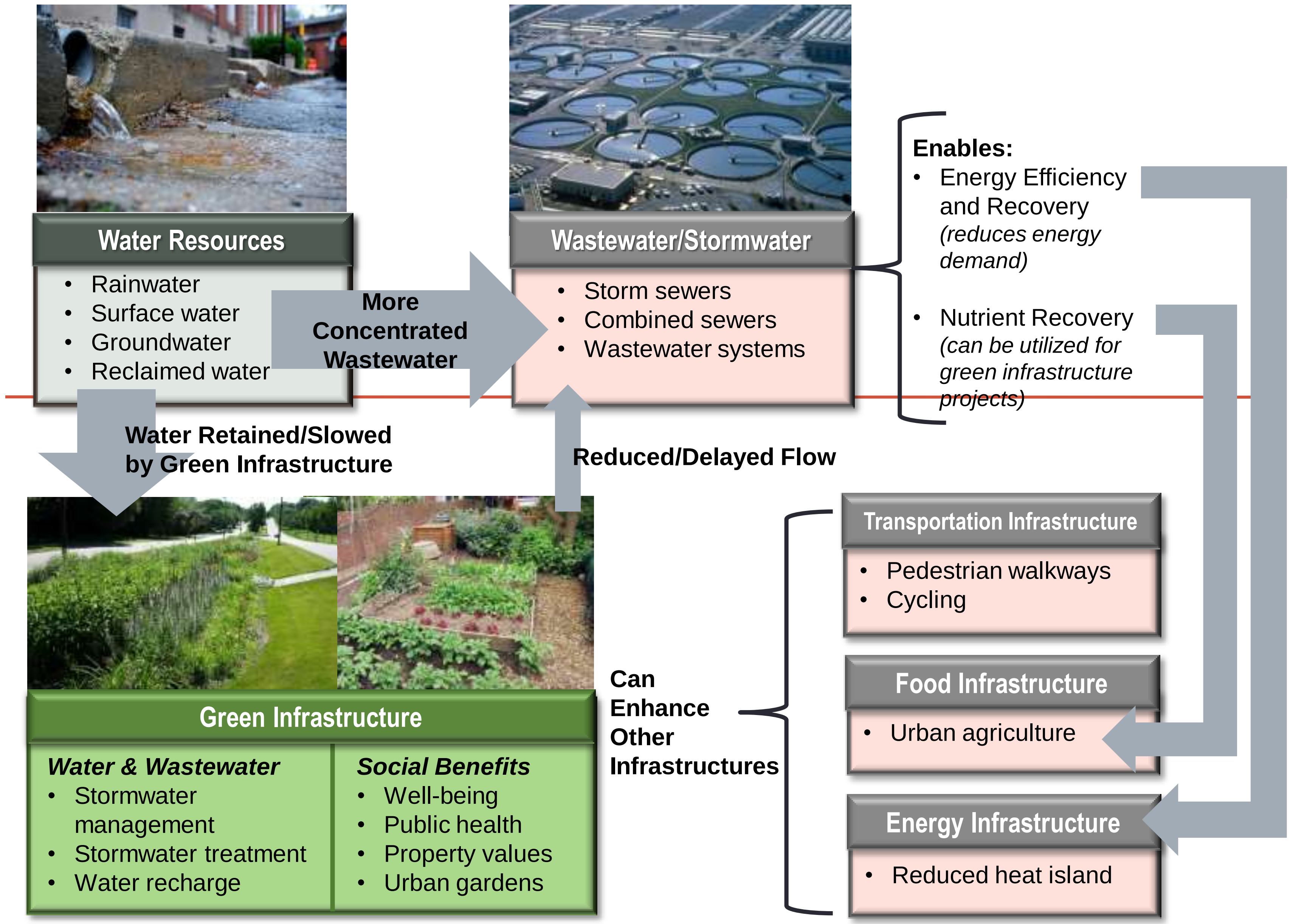
9. Maximize the creation of comfort & wealth

10. Take advantage of socioeconomics as a driver in achieving change.

11. Require adaptive management as the policy strategy

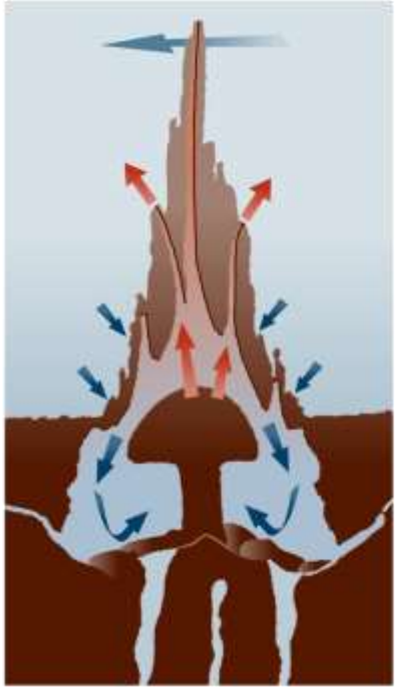
12. Utilize renewable flows rather than depleting stocks

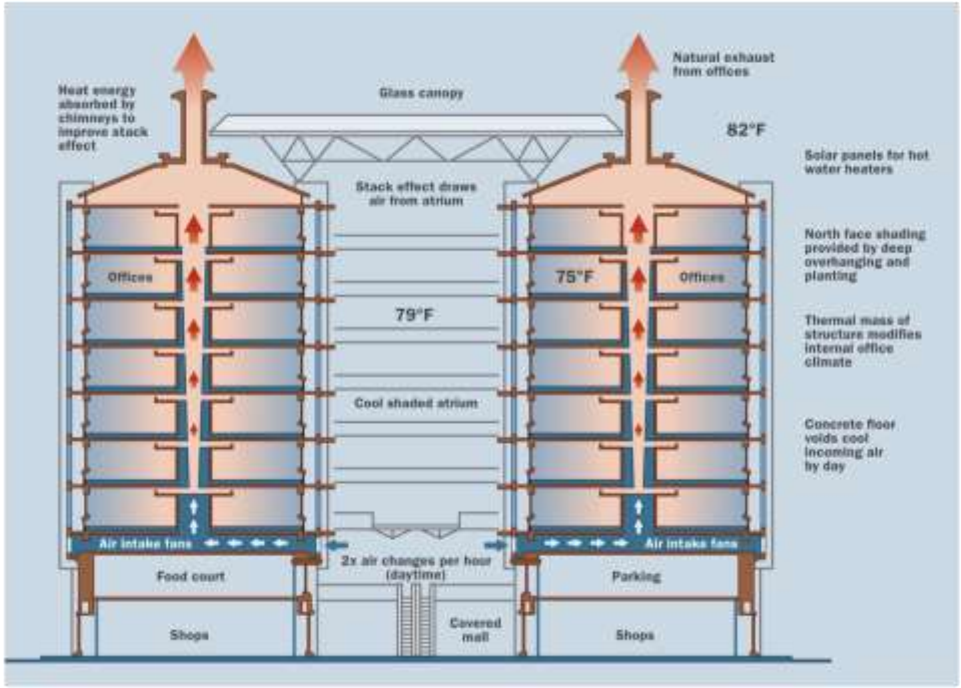
System-based Benefits of LID Best Management Practices



Bio-Inspired Design

Green Building in Zimbabwe Modeled After Termite Mounds: Passive Cooling





Source:
https://www.foe.co.uk/news/eastgate_centre_harare_termite_mound_41325

Data Enabled Product Design and Decision Making

What Atlanta Residents Care About In Terms of Investing Autonomous Vehicles: Topic Modeling

- 1,540 Comments
  - The threat to public transportation, 17.1%
  - Autonomous vehicles, 82.9%
    - Liability and safety improvement, 18.6%
    - Policy incentives, 15.8%
    - Prerequisites for autonomous vehicles on road, 15.6%
    - Impacts on traffic congestion, 5.5%
    - The handling of autonomous vehicles, 12.7%
    - Cyber security, 14.7%

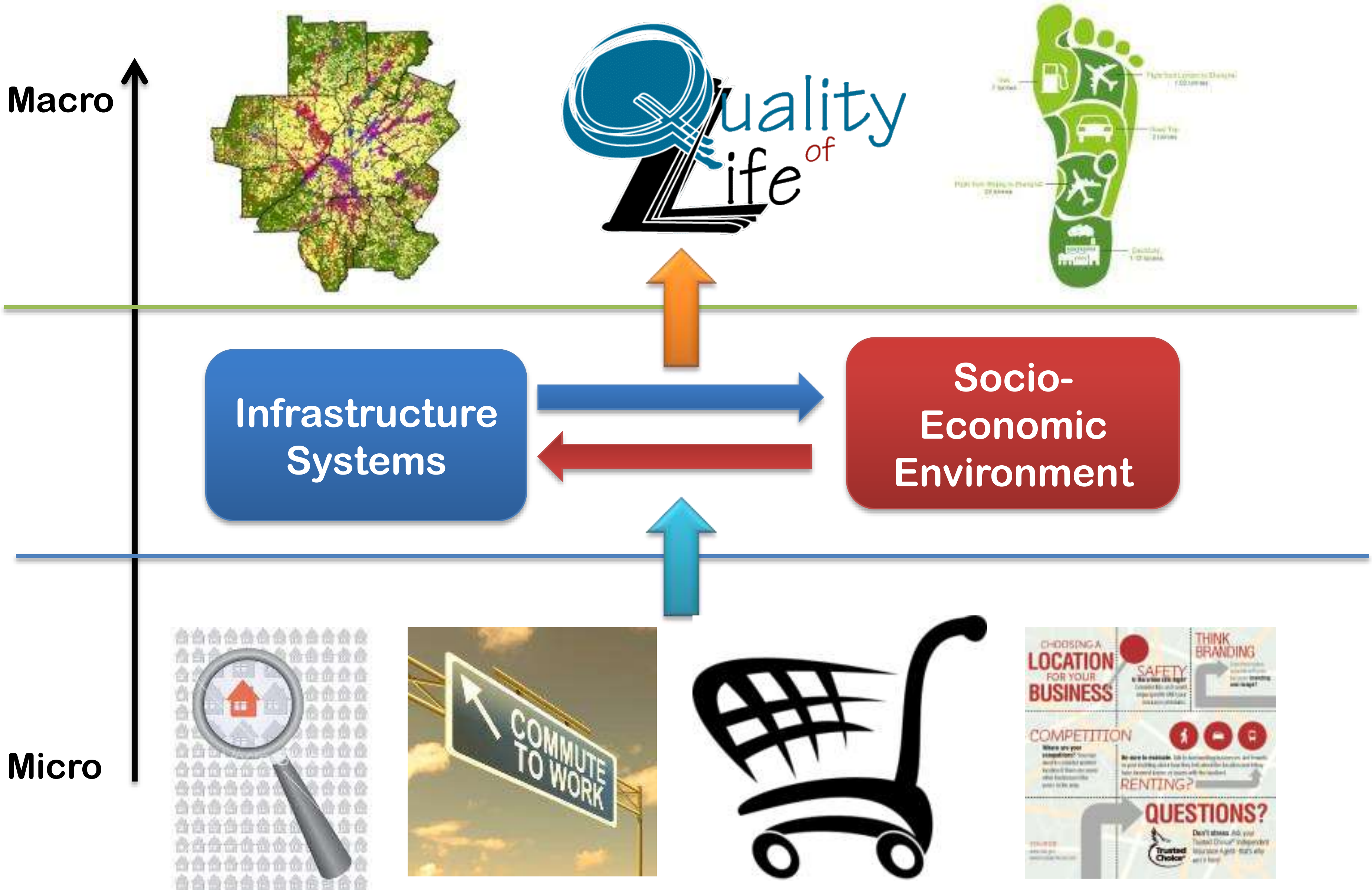
Crowdsourcing for Citizen Engagement

- **Mechanical Turk** is a cost-effective platform for collecting survey responses in a short period.
- Previous studies that compared Mechanical Turk with laboratory experiments and traditional web studies have shown that the self-selection bias of the sample (e.g., people who are not interested in the topic of the survey may not answer the survey) is smaller using mechanical Turk than traditional web-based surveys. The data quality Turk has been shown to be comparable to that of laboratory

- We developed a survey measuring Atlanta residents' preference for low-impact and transit-oriented development.
- 764 useful responses were collected from a total of 811 responses from Mechanical Turk within three weeks.

Complexity Management of Urban Systems

Emergence of desirable amenities (high Tax Revenue and Quality of Life) & undesirable amenities (e.g., poor air quality, low tax revenue, traffic congestion, flooding, etc.)



Big Data for Social Decision and Complexity Modeling

Topic Modeling

Collect

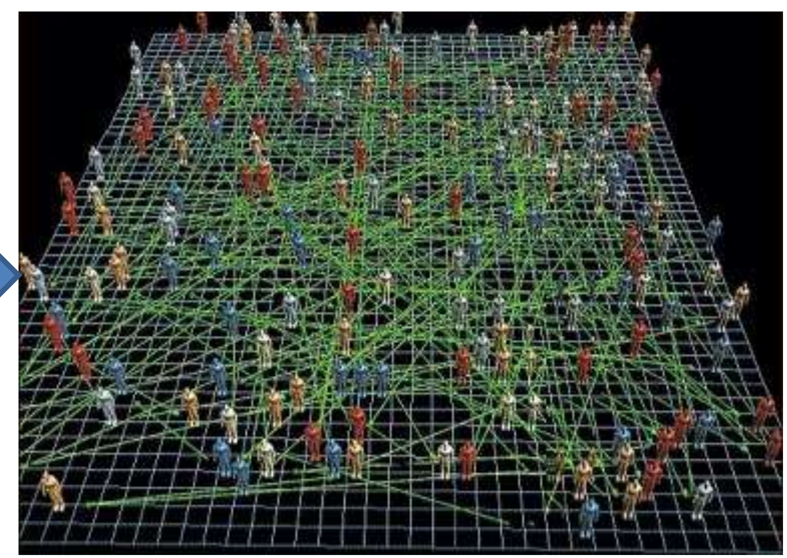
- Social Media
- Blogs
- Twitter
- News
- Product Reviews

Analyze

- Enrich and prepare social media content with metadata

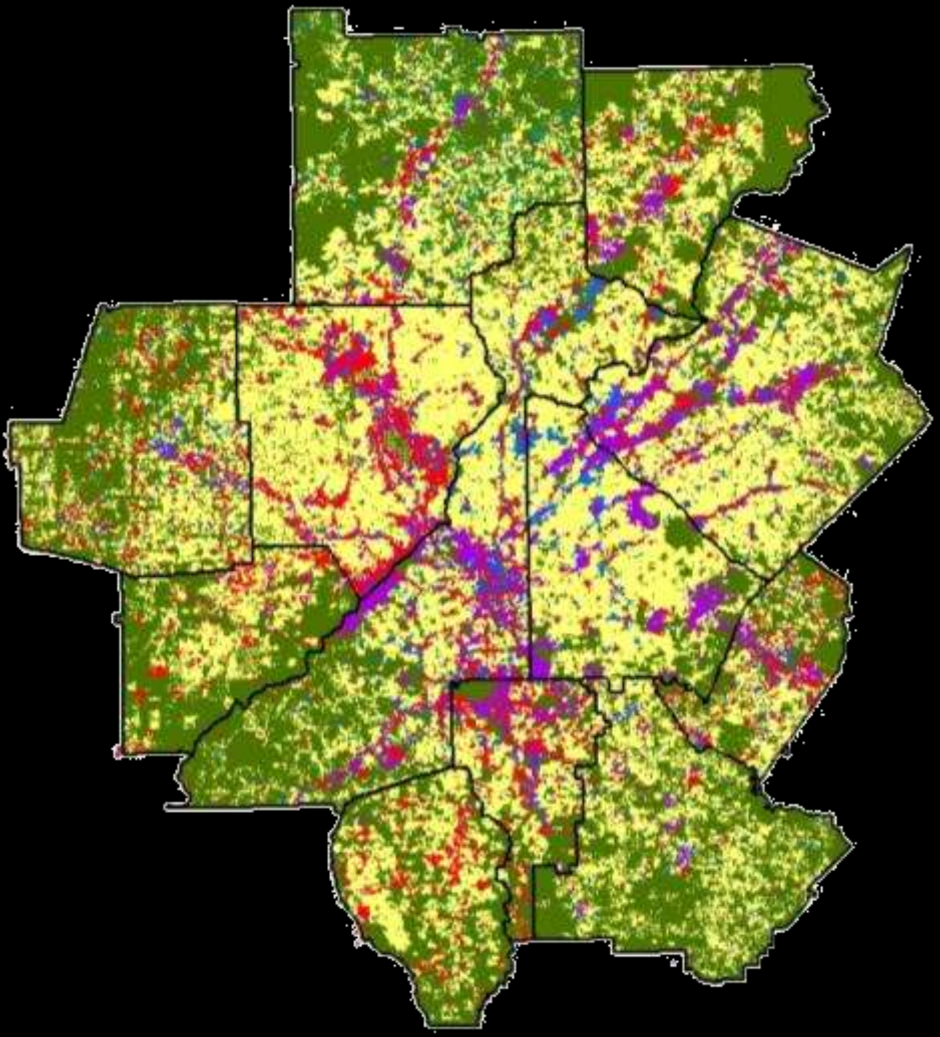
Modeling

- Agent-based urban model and visualization

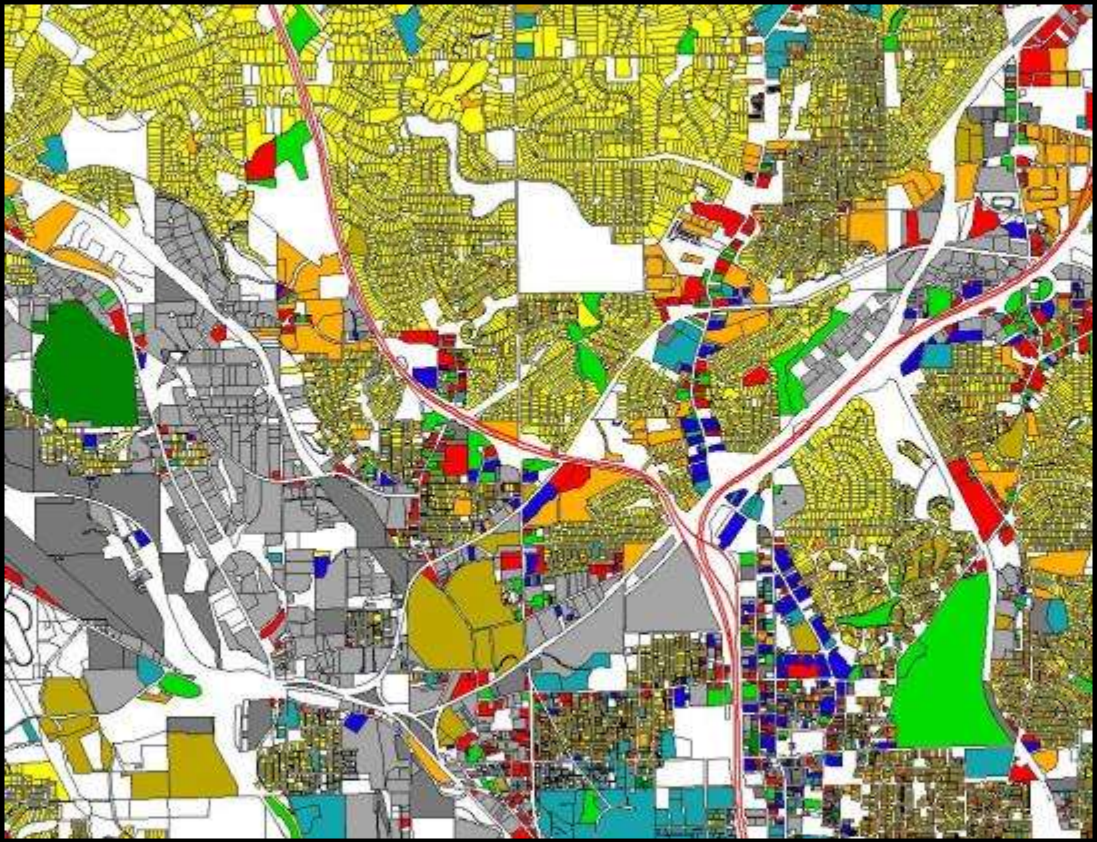


Spatial Databases for Urban Modeling

- The SMARTRAQ project
  - Supports research on land use impact on transportation and air quality
  - 1.3 million parcels in the 13 metropolitan Atlanta non-attainment counties



SMARTRAQ Data and Attributes



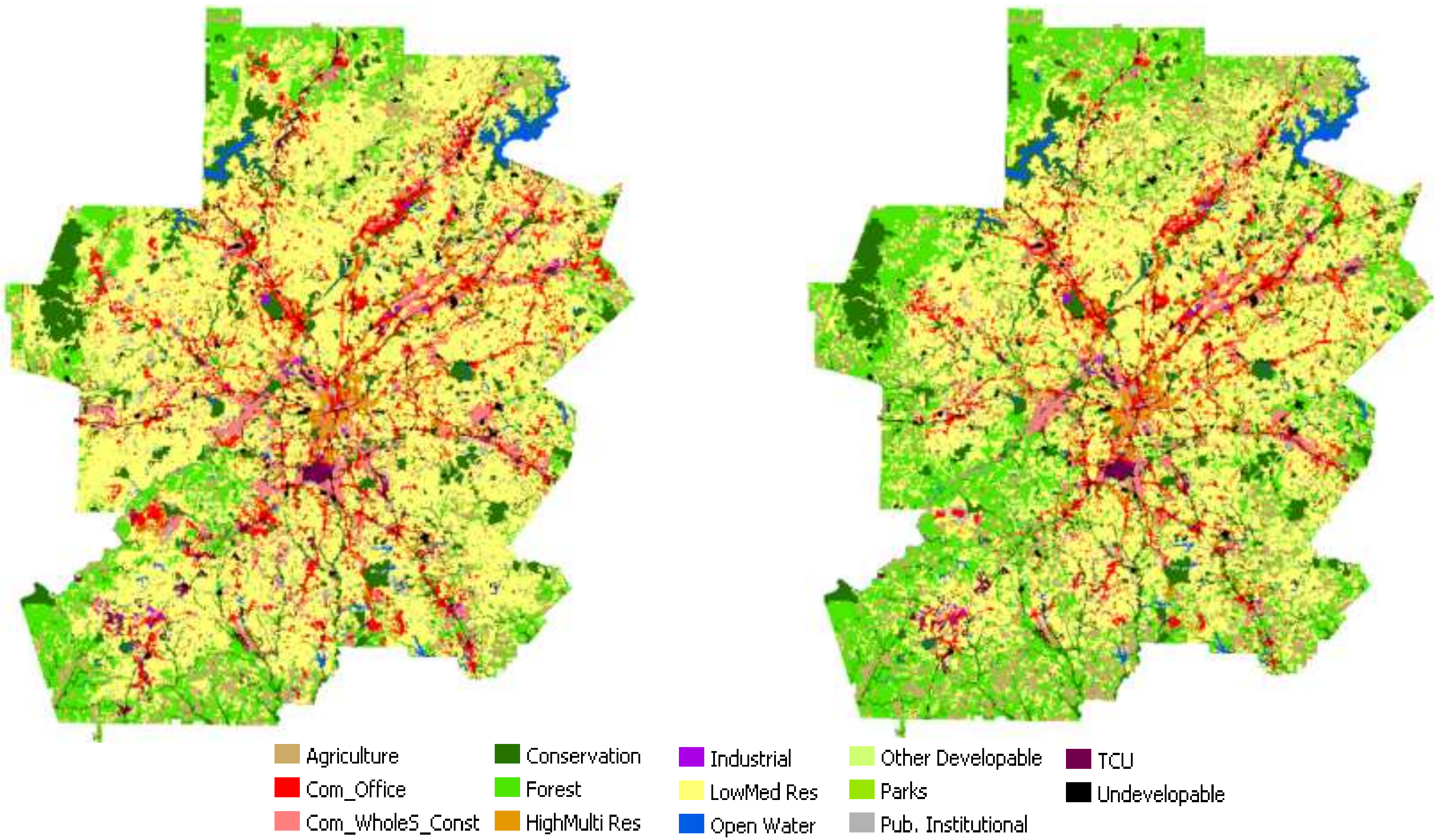
- Land Use Type
- Number of Units
- X,Y Coordinate
- Estimated Sq Feet
- Total Sq Feet

- Address
- Road Type
- City
- Zip Code
- Owner Occupied
- Commercial/Residential
- Zoning
- Sale Price
- Sale Date
- Tax Value
- Assessed Value
- Improvement Value
- Land Value
- Year Built
- No. of Stories
- Bedrooms
- Parking
- Acreage

Projected Growth Scenarios for Atlanta

Business As Usual Year 2030

More Compact Development Year 2030



Decentralized Energy Production at Perkins + Will, Atlanta Office

- Air Cooled Microturbines are used to for heating and cooling using Absorption Chillers and supply 40% of the total electricity.

Adding Distributed Generation as part of the Grid:

Water Reduction: >50%
CO_2 Reduction: 15 - 40%
NO_X Reduction: ~90%

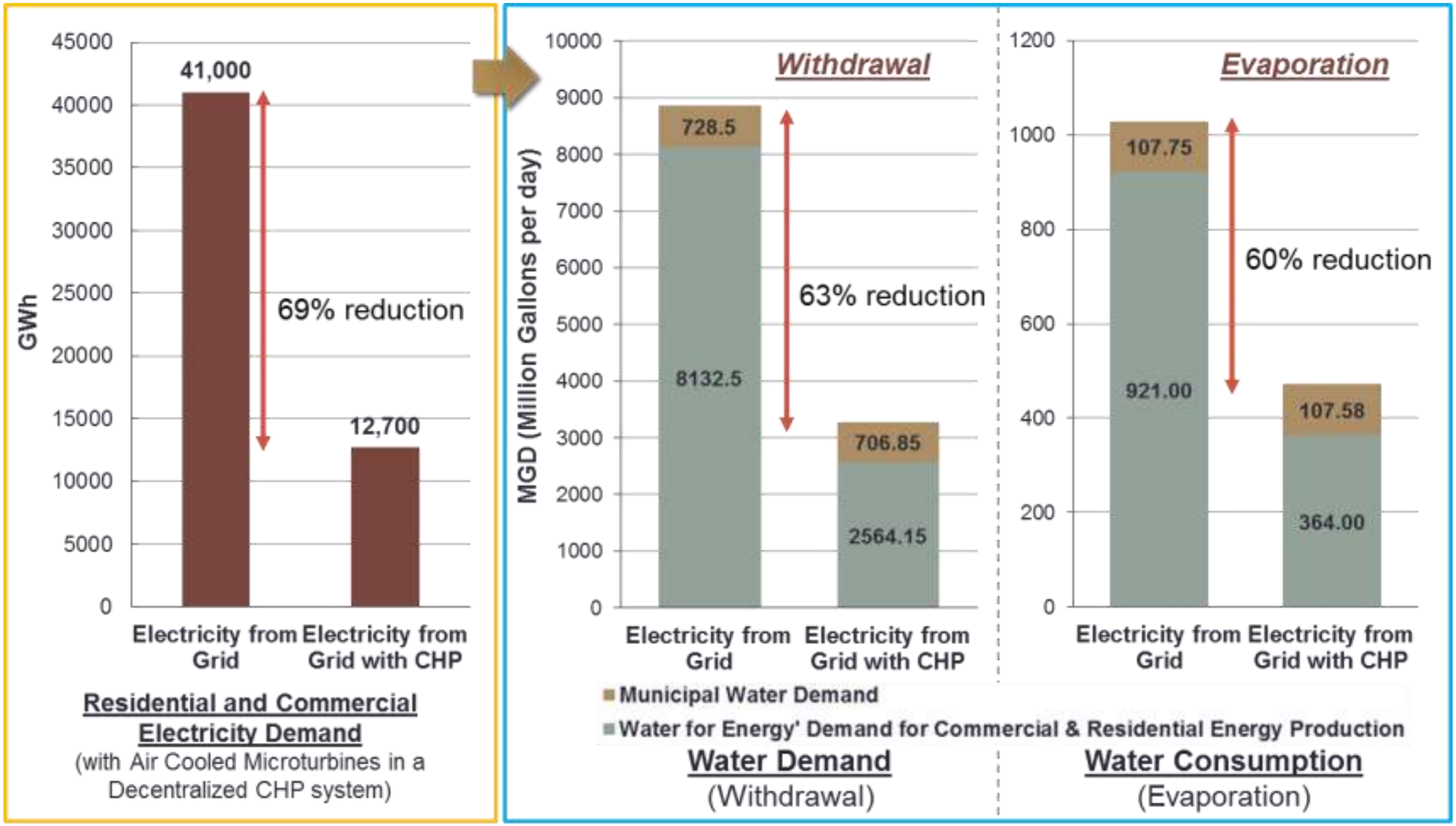
Adsorption Chiller

65 kW Microturbine

Perkins+Will Office Building

Atlanta Energy and Water Demand Projections for More Compact Development

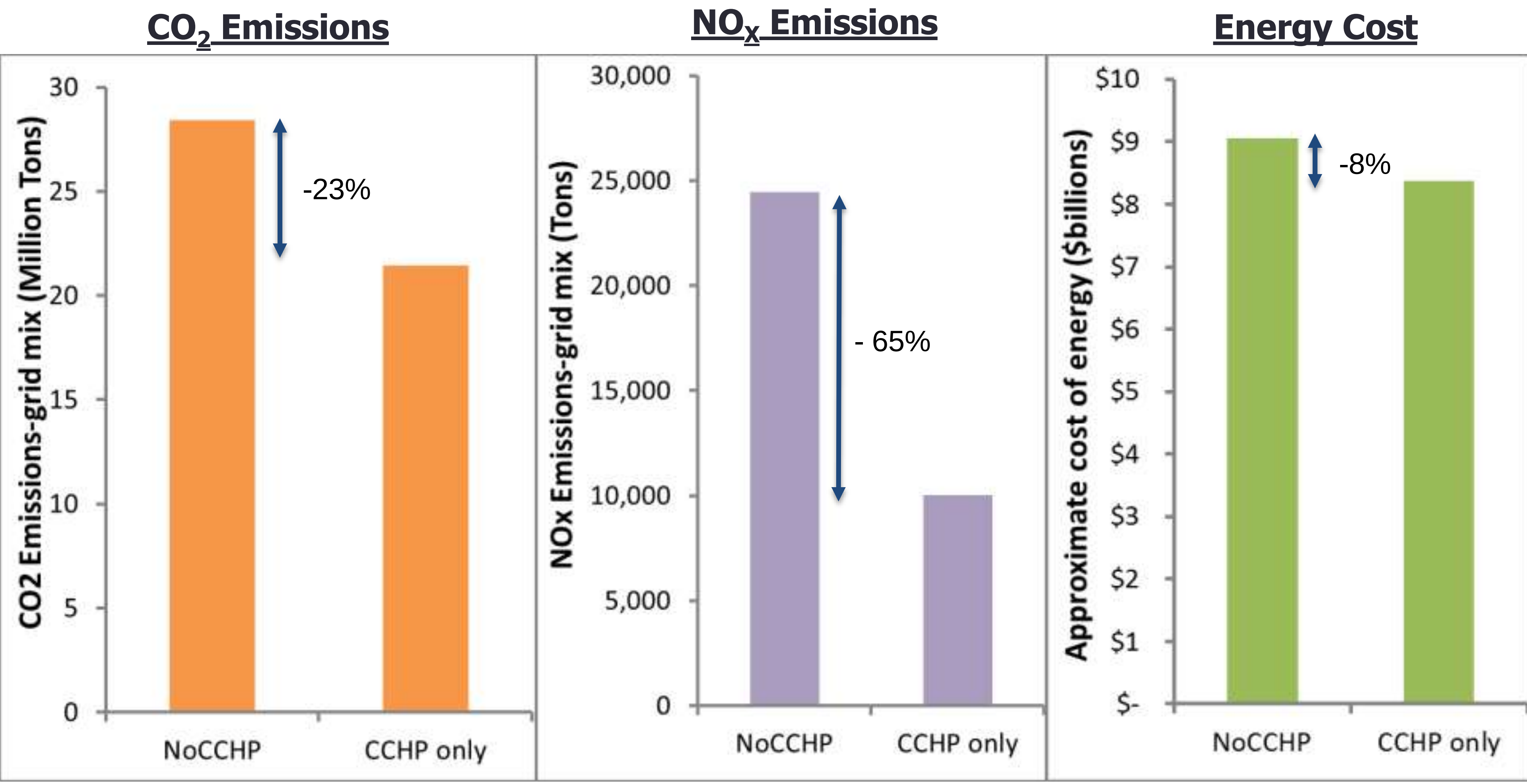
(with low flow fixtures + decentralized CCHP system)



Social Decision Making: Managing the Complexity → Predicting the Demand for Urban Infrastructure → Identifying Sustainable and Resilient Alternatives → Evaluating Sustainability & Resilience Performance

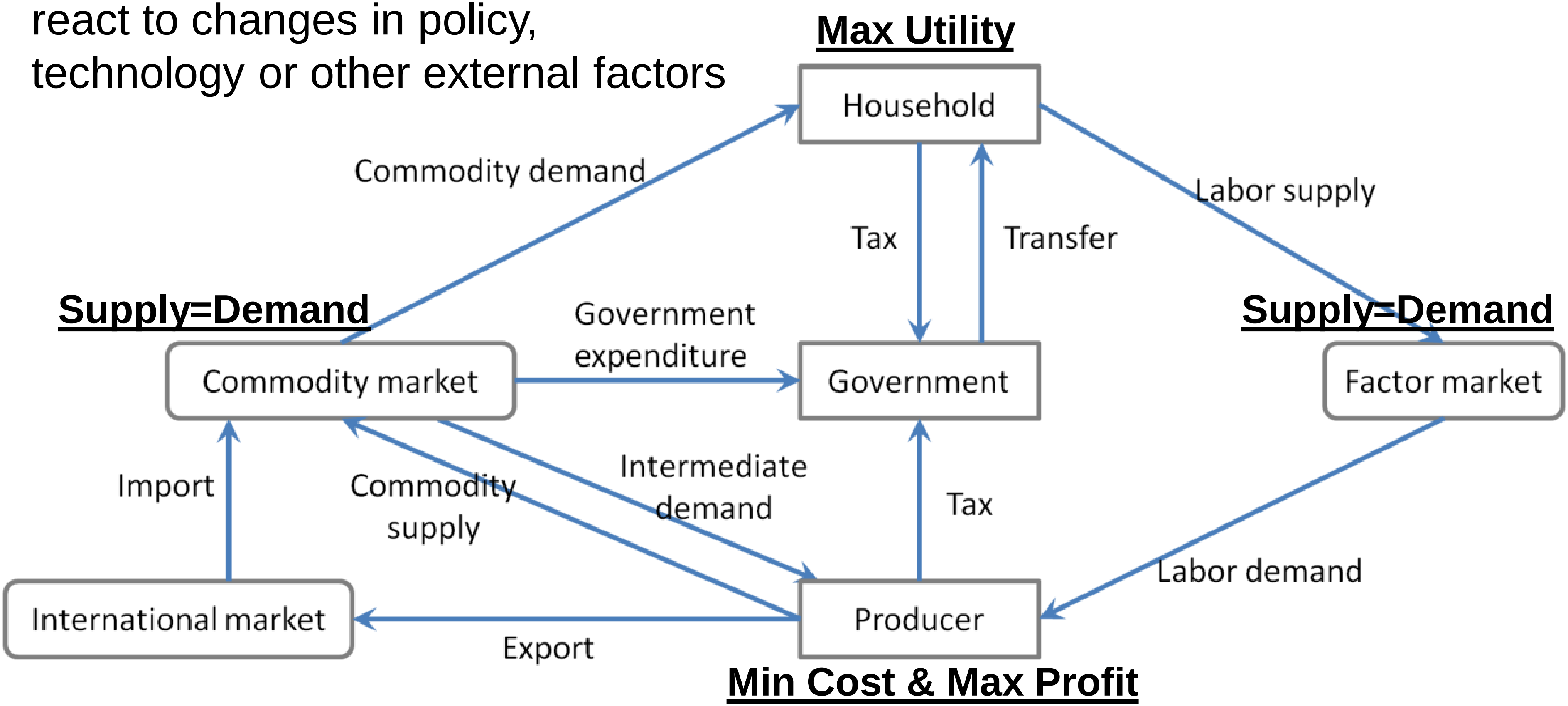
Potential GHG and Cost Reductions in 2030

By 2030, implementation of CHP in all new residential and commercial buildings will reduce the CO_2 emissions by~ 0.007 Gt CO_2, NOx emissions by ~ 15000 Tons ,and the energy costs by $680 million per year for the Metro Atlanta region.



Complex Economy Systems: A Computable General Equilibrium (CGE) Model

- Estimate how an economy might react to changes in policy, technology or other external factors



Equilibrium changes with different initial conditions
-Updates between periods (population migration, capital depreciation, etc)
-External shocks (efficiency change, tax, etc)

Network Analysis

Modeling the urban system using **Ecosystem Network Analysis (bio-inspired)**

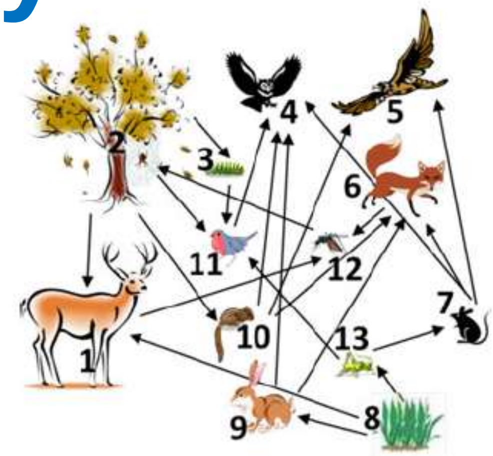
- Natural ecosystem health is dependent on **stability** and **sustainability**

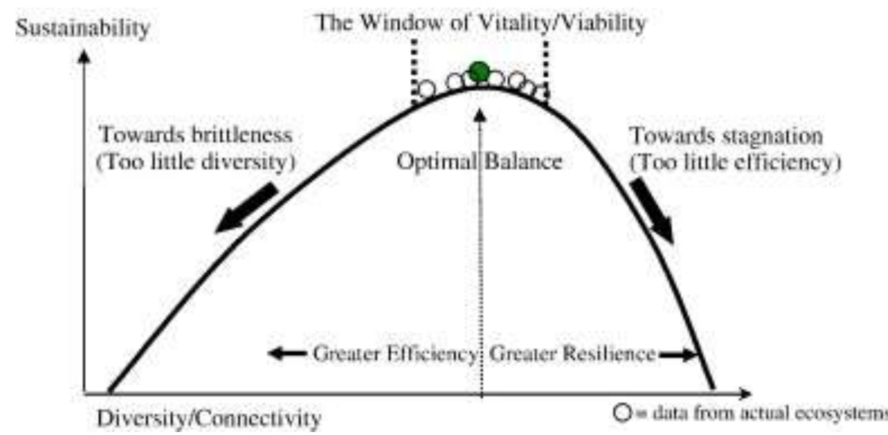
Quantify:

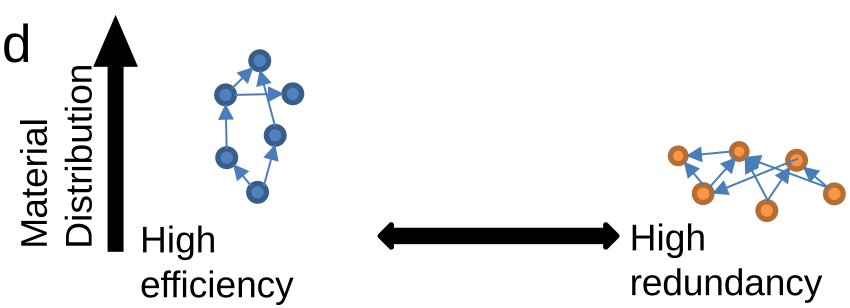
- Flows
- Connectivity
- Cyclicity
- Robustness of the network

Tradeoffs between efficiency and redundancy

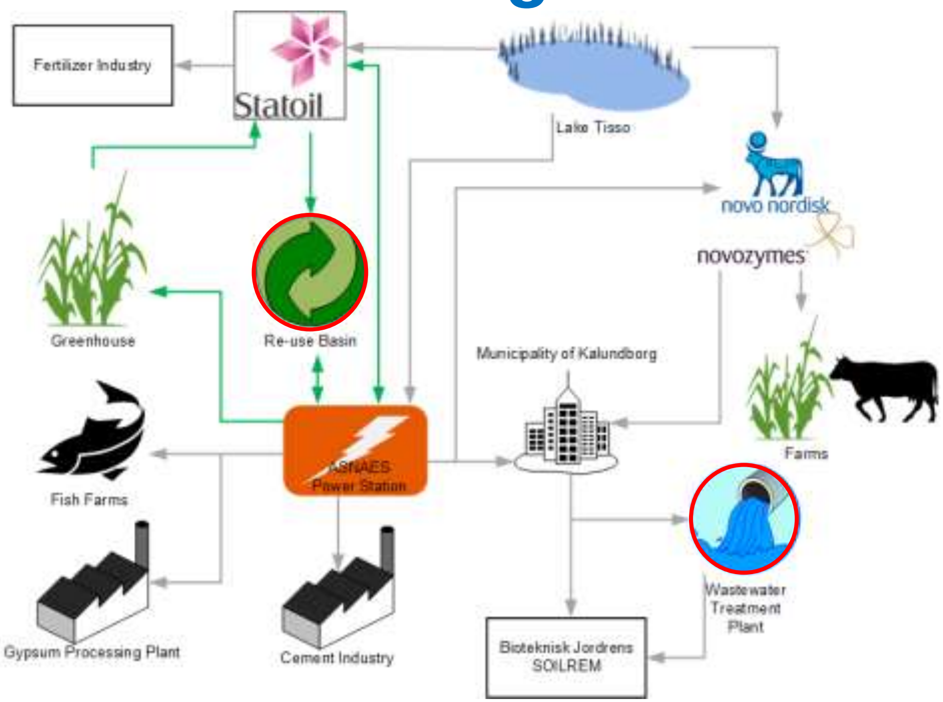
- High efficiency – less ability to respond to stress
- High redundancy – decreased development and competition



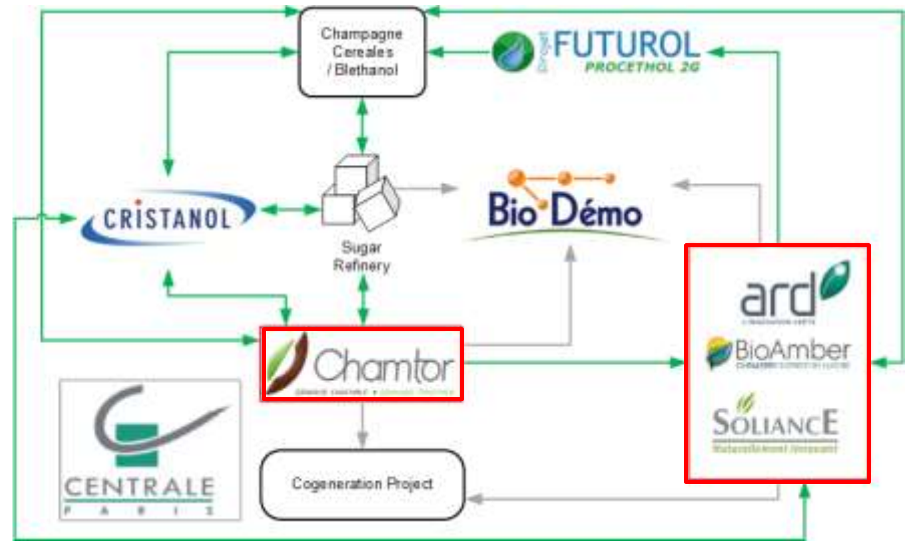




Internal Materials and Energy Cycling of Ecological Industrial Parks (EIP)



Kalundborg EIP



Pomacle-Bazancourt EIP

- Green arrows represent linkages which participate in a cycle, greyed out linkages do not.
- **The more material and energy recycling increases the environmental performance of the EIP.**
- Pomacle-Bazancourt EIP is best performer among 48 EIPs.
- Kalundborg EIP is mediocre performing EIP.

Credit: Bert Bras and Marc Weissburg, GT

Natural ecosystems have more cycling

Indices of Network Resilience (INR)

Developed through analysis of network topology.

Provides an indicator about how the topology affects the resilience of the network.

- The INR is calculated through a Monte Carlo Analysis (MCA) model considering the following six graph properties:
  - Graph Diameter (d)
  - Characteristic Path Length (l)
  - Central-point dominance (c'_b)
  - Critical ratio of defragmentation (f_C)
  - Algebraic Connectivity (λ_2)
  - Meshedness Coefficient (r_m)

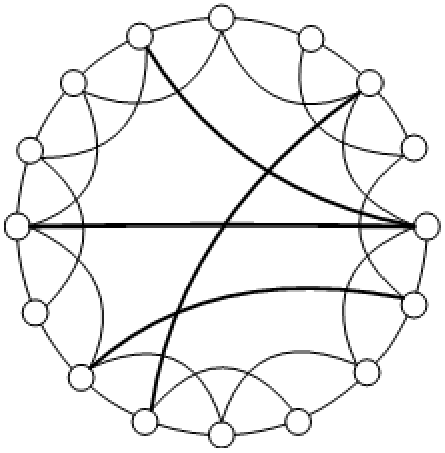
The first two attributes are related to the efficiency of the system, the third reflects the dominance of a particular node in maintaining the integrity of the network, and the last three are surrogate measures of the robustness and path redundancy of the network to failure of one or more nodes or links

Network Analysis

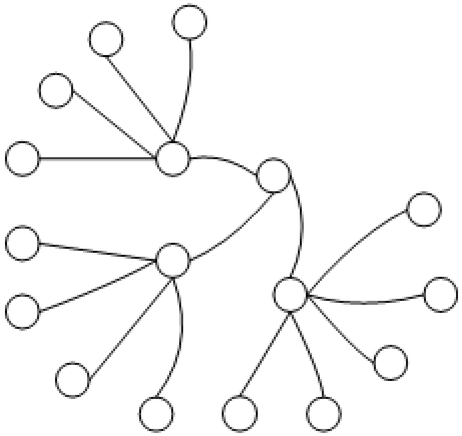
Trade-off between network properties

a) Small World
b) Scale Free
c) Randomness
d) Fractal

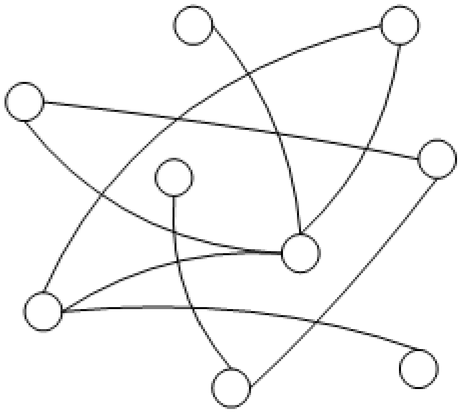
(a) Small World Network



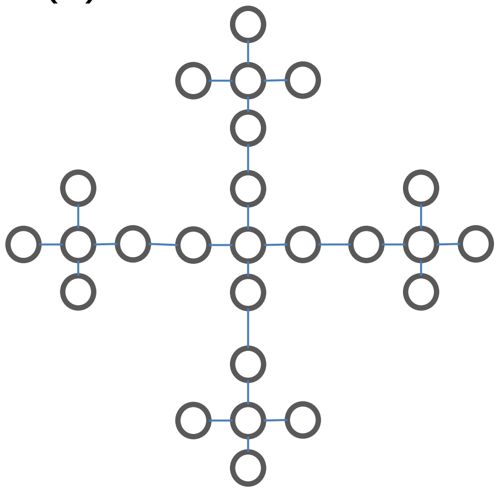
(b) Scale Free Network



(c) Random Network

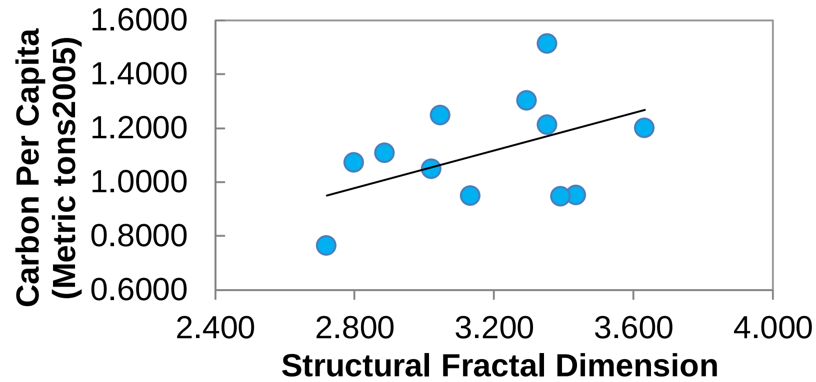


(d) Fractal Network

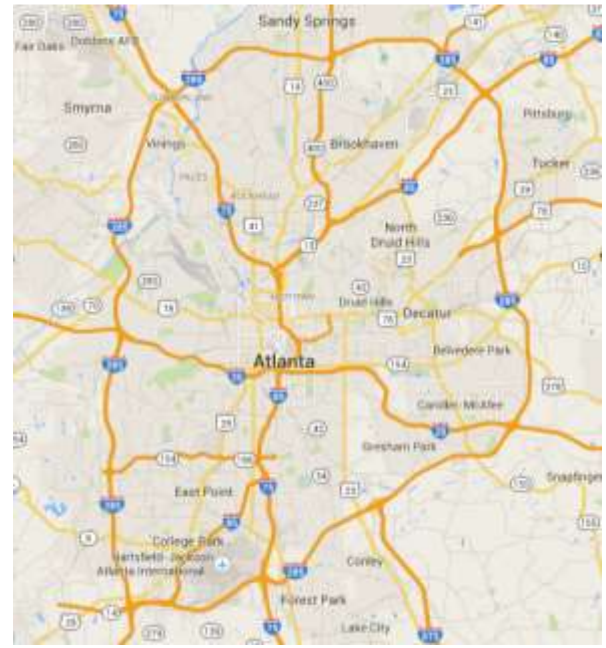


Source: Chung-Yuan Huang et al., 2015

The Impact of the Hierarchy of Transportation Network On Land Development and Transportation Carbon Emissions



2 miles



3,258 Person Per Square Mile
1.07 metric ton per capita per year
Structural Fractal Dimension = 2.80

1,378 Person Per Square Mile
1.52 metric ton per capita per year
Structural Fractal Dimension = 3.36

The geometric form of road network is similar between Washington DC and Atlanta. The difference in the hierarchy of transportation network accounts for *30%* of density difference and *20%* of carbon difference between Washington DC and Atlanta.

Grids Closing the Loops on Carbon, Water, Nutrients, Material Flows

- To become more sustainable and resilient, we need coordinate and restructure at least 8 important grids. They include: (1) nutrients, (2) natural gas, (3) water, (4) electricity, (5) thermal, (6) transportation, (7) materials, and (8) carbon grids.
- In past, these grids were mostly constructed in isolation and we did not consider there interactions.

Environmental Costing Account

- Compare the environmental costs of different raw material inputs, processes, locations, suppliers and product life stages
- Understand opportunities to optimize company operations, supply chains and products in line with global resource availability and environmental cost
- Identify financial risk from natural resource constraints and regulatory frameworks
- Provide transparency of environmental performance to business managers, customers, investors and stakeholders

PUMA Environmental Cost Account

Area	Typical activities		
PUMA Operations	• Offices • Shops	• Warehouses • Business travel	• Logistics • IT
Tier 1 suppliers	• Shoe manufacturing	• Apparel manufacturing	• Accessory manufacturing
Tier 2 suppliers	• Outsole production • Insole production	• Textile embroidery and cutting • Adhesive and paint production	
Tier 3 Suppliers	• Leather tanning • Petroleum refining	• Cotton weaving and dyeing	
Tier 4 suppliers	• Cattle rearing • Rubber plantations	• Cotton farming • Petroleum production	• Other material production

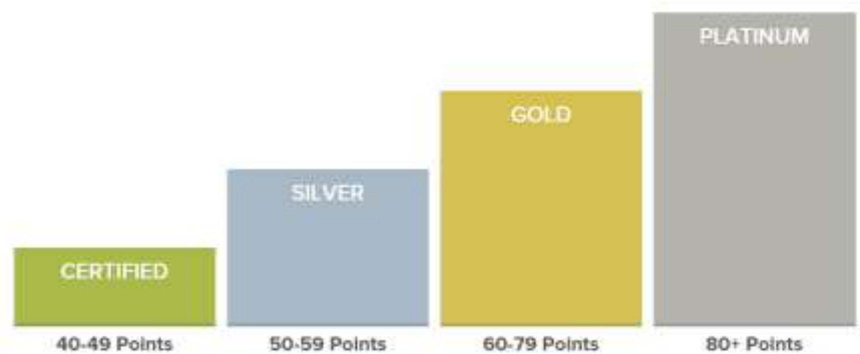
Source: Trucost.

LEED (Leadership in Energy & Environmental Design)

- ❑ There are five rating systems that address multiple project types

- ❑ The LEED checklist across five categories (LEED for new construction)
  - ➢ Sustainable Cities, 26 possible points
  - ➢ Water Efficiency, 10 possible points
  - ➢ Energy and Atmosphere, 35 possible points
  - ➢ Materials and Resources, 14 possible points
  - ➢ Indoor Environmental Quality, 15 possible points

- ❑ The number of points a project earns determines the level of LEED certification.



Source: US Green Building Council; http://built-envi.com/do-leed-buildings-save-energy-yes-no-it-depends/

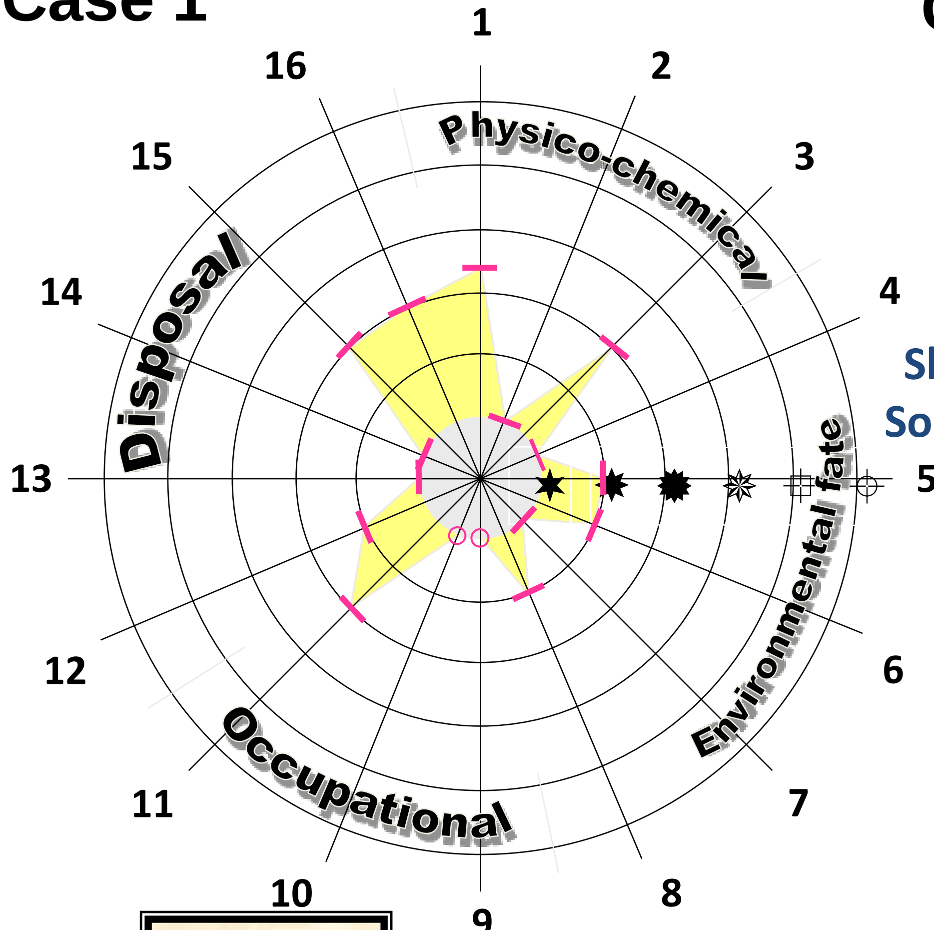
ENVISION™ Rating System

- Envision measures the sustainability of an infrastructure project from design though construction and maintenance.
- The Envision® has 60 sustainability criteria, called credits, divided into five sections: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk.

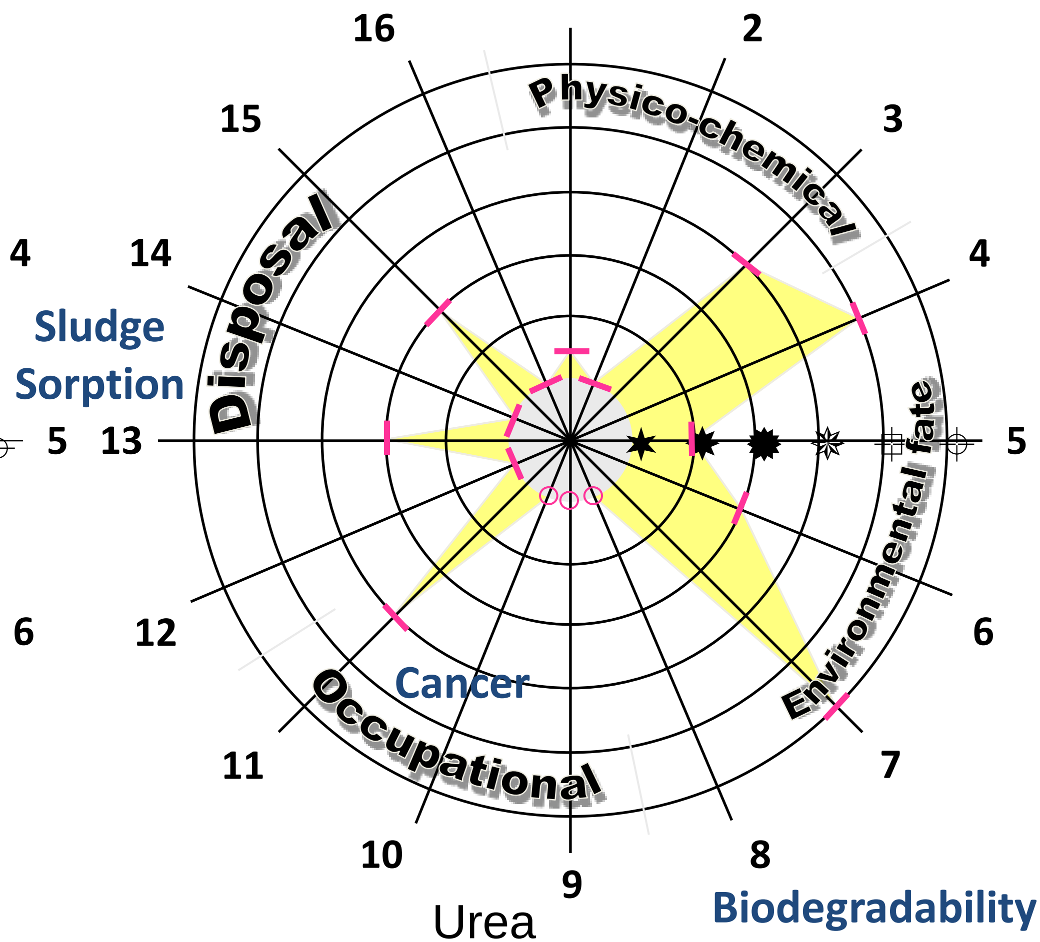
Source: http://www.hdrinc.com/about-hdr/sustainability/envision

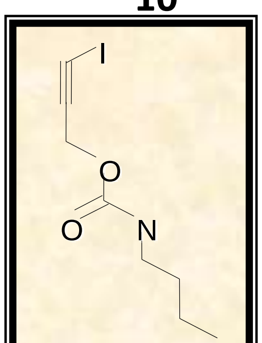
Target Plot: Fungicide

Case 1



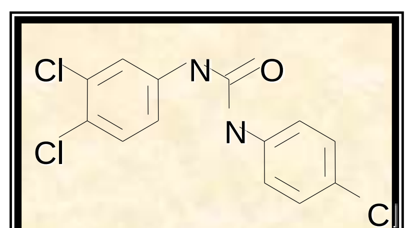
Case 2





Carbamate

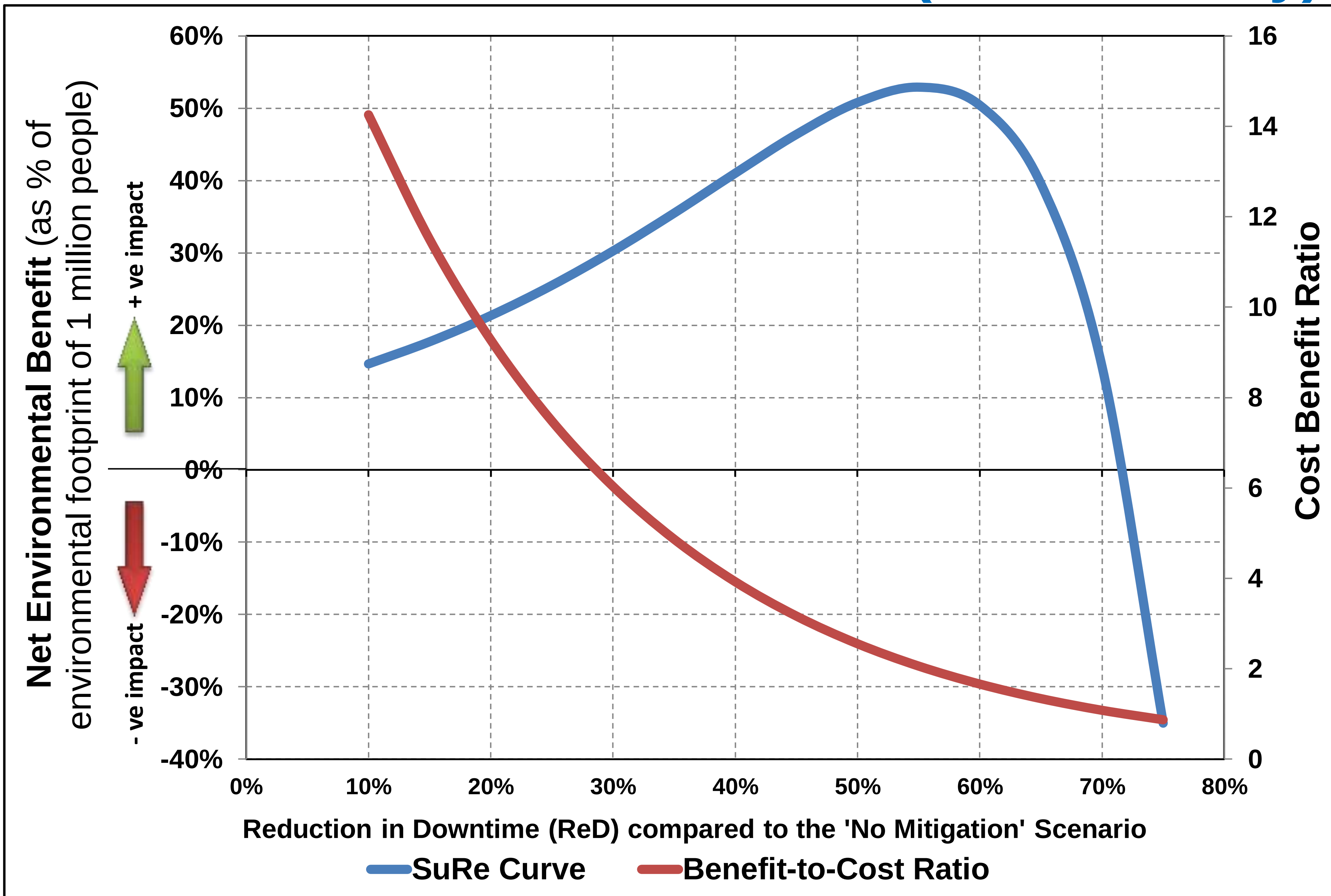
wastewater treatment of carbamate should be of concern due to its aquatic toxicity



Urea

the urea presents a higher risk due to its higher carcinogenic potential and its transport with the sludge

Optimizing Sustainability, Resilience and Cost for 165 miles Water Main (Hetch Hachy)



INTERNATIAONAL CONFERENCE ON SUSTAINABLE INFRASTRUCTURE - ICSI 2016

A Sustainable Future for China, the Asian Region and the Globe

October 17-19, 2016
Shenzhen, People's Republic of China

Invitation to the Follow-on Conference to the 2014 ICSI

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Dates for ICSI 2016

- Announcement and Call for Papers: January, 2016
- Abstracts Due: March 31, 2016
- Abstract Acceptance: May 15, 2016
- Final Manuscripts Due: June 30, 2016
- Mail Invitation Letters to all the Attendees for Visa Purposes: June 30, 2016
- Registration Open: July – August, 2016
- Opening of ICSI 2016: October 17, 2016

PV System at Georgia Tech Aquatic Center (1996)

THANK YOU!

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- And more…

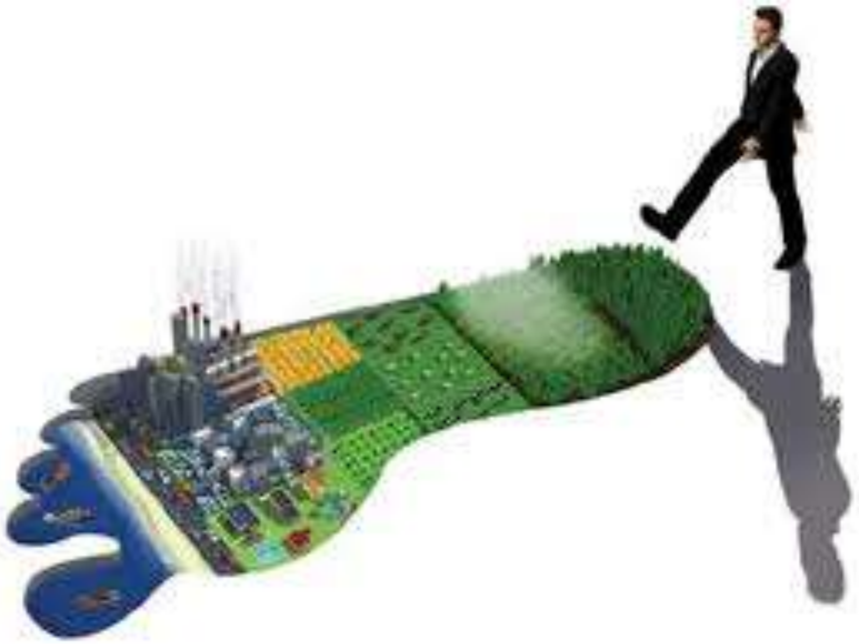
Back-up Slides on Sustainability Metrics

Contents:

- Ecological Footprint
- Carbon Footprint
- Water Footprint
- Genuine Progress Indicator
- Happy Planet Index
- Human Development Index
- Environmental Sustainability Index

What is Ecological Footprint?

- **Ecological Footprint** can be defined as *“the biologically productive and mutually exclusive areas necessary to continuously provide for people’s resource supplies and the absorption of their wastes”*



Ecological Footprint and Biocapacity Accounting

Ecological Footprint and biocapacity accounting is based on six fundamental assumptions (Wackernagel 2002):

1. ***The majority of the resources people or activities consume and the wastes they generate can be tracked.***

2. ***Most of these resource and waste flows can be measured in terms of the biologically productive area necessary to maintain them***. Resource and waste flows that cannot be measured in terms of biologically productive area are excluded from the assessment, leading to a systematic underestimate of the total demand these flows place on ecosystems.

3. ***By scaling each area in proportion to its bioproductivity, different types of areas can be converted into the common unit of average bioproductivity, the global hectare.*** This unit is used to express both Footprint and biocapacity.

Ecological Footprint and Biocapacity Accounting

4. ***Because a global hectare of demand represents a particular use that excludes any other use tracked by the Footprint, and all global hectares in any single year represent the same amount of bioproductivity, they can be summed.*** Together, they represent the aggregate demand or Ecological Footprint. In the same way, each hectare of productive area can be scaled according to its bioproductivity and then added up to calculate Biocapacity.

5. ***As both are expressed in global hectares, human demand*** (as measured by Ecological Footprint accounts) ***can be directly compared to global, regional, national, or local biocapacity.***

6. ***Area demanded can exceed the area available.*** If demand on a particular ecosystem exceeds that ecosystem's regenerative capacity, the ecological assets are being diminished. When the demand exceeds available biocapacity, it is referred to as ***ecological overshoot***.

Carbon Footprint

- A **carbon footprint** is a measurement of all greenhouse gases the individuals produce and has units of tonnes (or kg) of carbon dioxide equivalent.
- A carbon footprint is made up of the sum of two parts, the primary footprint and the secondary footprint

1. The **primary footprint** is a measure of our direct emissions of CO_2 from the burning of fossil fuels including domestic energy consumption and transportation (e.g. car and plane). We have direct control over these.
2. The **secondary footprint** is a measure of the indirect CO_2 emissions from the whole lifecycle of products we use - those associated with their manufacture and eventual breakdown. To put it very simply – the more we buy the more emissions will be caused on our behalf.

Source: www.carbonfootprint.com

What is water footprint?

- The **water footprint** of an individual, community or business is defined as the total volume of freshwater used to produce the goods and services consumed by the individual or community or produced by the business.
- Water use is measured in water volume consumed (evaporated) and/or polluted per unit of time.
- The water footprint is a geographically explicit indicator, not only showing volumes of water use and pollution, but also the locations.
- However, the water footprint does **NOT** provide information on <u>how the embedded water negatively or positively affects local water resources, ecosystems and livelihoods.</u>
- The water footprint of an individual consumer refers to the ***sum of direct and indirect freshwater use*** by the consumer.
  - The direct water use is the water used at home.
  - The indirect water use relates to the total volume of freshwater that is used to produce the goods and services consumed by the consumer.

The water footprint of a product

Green water footprint

- volume of rainwater evapor ted or incorporated into product.


- volume of surface or groun ater evaporated,incorporated into product or returned to othe nt or the sea.


Grey water footprint

- volume of polluted water.


Source: Hoekstra et al., 2011

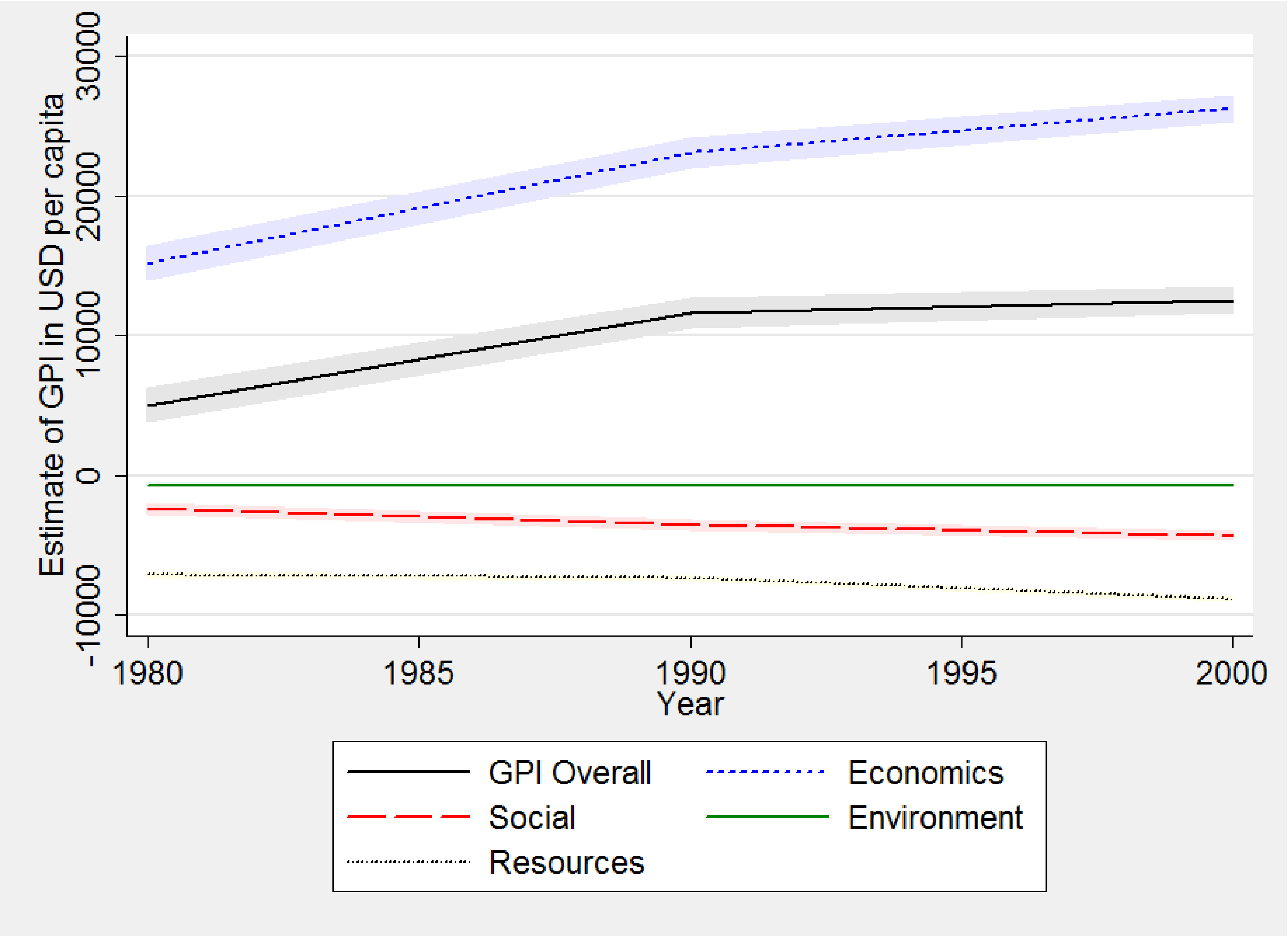
GPI Methodology

- The GPI is derived from 26 measures spanning the triple-bottom line of sustainability

Personal Consumption (+)	**Loss of Leisure Time (-)**	**Loss of Wetlands (-)**
Income Distribution Index (+/-)	**Costs of Under-employment (-)**	**Loss of Farmlands (-)**
Weighted Personal Consumption (+)	**Cost of Consumer Durables (+)**	**Loss of Primary Forests (-)**
Value of Housework and Parenting (+)	**Cost of Commuting (+)**	**Resource Depletion (-)**
Value of Higher Education (+)	**Cost of Household Pollution Abatement (-)**	**CO_2 emissions damage (-)**
Value of Volunteer Work (+)	**Cost of Auto Accidents (-)**	**Cost of O_3 depletion (-)**
Services of Consumer Durables (+)	**Cost of Water Pollution (-)**	**Net Capital Investment (+/-)**
Services of Highways (+)	**Cost of Air Pollution (-)**	**Net Foreign Borrowing (+/-)**
Costs of Crime (-)	**Cost of Noise Pollution (-)**	

Source: The Genuine Progress Indicator: Summary of Data and Methodology,

GPI for Metro Atlanta



What is HPI?

- The **Happy Planet Index (HPI)** is an index of human well-being and environmental impact that was introduced by the New Economics Foundation (NEF) in July 2006.
- It operationalizes the IUCN's (World Conservation Union) call for a metric capable of measuring ***'the production of human well-being (not necessarily material goods) per unit of extraction of or imposition upon nature'***
- Human well-being is operationalized as ***Happy Life Years -*** which can be seen as happiness-adjusted life expectancy
- Extraction of or imposition upon nature is proxied for using the ecological footprint per capita
- In essence, ***HPI is an efficiency measure:*** <u>the degree to which long and happy lives</u> (life satisfaction and life expectancy are multiplied together to calculate happy life years) <u>are achieved per unit of environmental impact.</u>

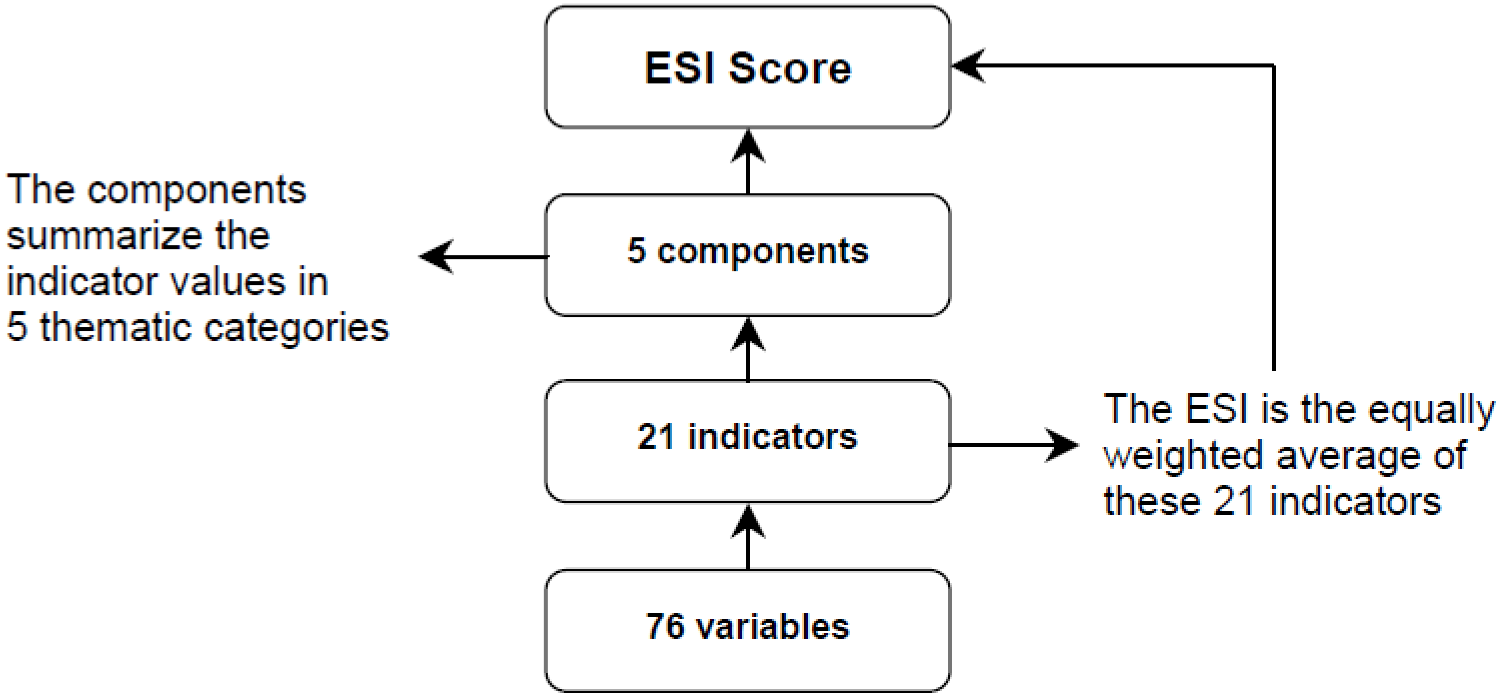
Source: The Happy Planet Index 2.0

Human Development Index (HDI)

- The Human Development Report introduced a new way of measuring development by combining indicators of life expectancy, educational attainment and income into a composite ***human development index.***
- HDI is a single statistic which serves as a frame of reference for both social and economic development.
- The HDI sets a minimum and a maximum for each dimension, called ***goalposts***, and then shows where each country stands in relation to these goalposts, expressed as a ***value between 0 and 1***.
- The life expectancy at birth component of the HDI is calculated using a minimum value of 20 years and maximum value of 83.2 years.
- The decent standard of living component is measured by GNI per capita (PPP US$) instead of GDP per capita (PPP US$) The HDI uses the logarithm of income, to reflect the diminishing importance of income with increasing GNI.

Environmental Sustainability Index (ESI)

- The **Environmental Sustainability Index (ESI)** is a composite index that tracks 21 elements of environmental sustainability covering natural resource endowments, past and present pollution levels, environmental management efforts, contributions to protection of the global commons, and a society's capacity to improve its environmental performance over time.



Components of ESI

1. **Environmental Systems**
2. **Reducing Environmental Stresses**
3. **Reducing Human Vulnerability to Environmental Stresses**
4. **Societal and Institutional Capacity to Respond to Environmental Challenges**
5. **Global Stewardship**

Component	Logic
Environmental Systems	A country is more likely to be environmentally sustainable to the extent that its vital environmental systems are maintained at healthy levels, and to the extent to which levels are improving rather than deteriorating.
Reducing Environmental Stresses	A country is more likely to be environmentally sustainable if the levels of anthropogenic stress are low enough to engender no demonstrable harm to its environmental systems.
Reducing Human Vulnerability	A country is more likely to be environmentally sustainable to the extent that people and social systems are not vulnerable to environmental disturbances that affect basic human wellbeing; becoming less vulnerable is a sign that a society is on a track to greater sustainability.
Social and Institutional Capacity	A country is more likely to be environmentally sustainable to the extent that it has in place institutions and underlying social patterns of skills, attitudes, and networks that foster effective responses to environmental challenges.
Global Stewardship	A country is more likely to be environmentally sustainable if it cooperates with other countries to manage common environmental problems, and if it reduces negative transboundary environmental impacts on other countries to levels that cause no serious harm.

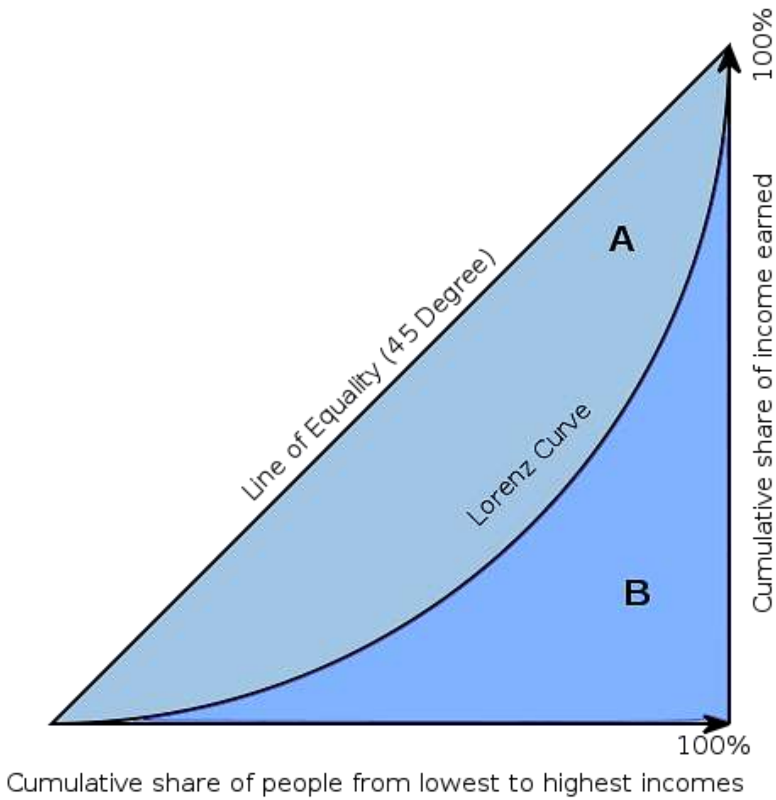
ESI v. Ecological Footprint Index

- The correlation between the two indices is negative, implying that large footprints tend to coincide with high ESI values.
- Since both indices measure certain aspects of sustainability, it might be counterintuitive.
- One explanation for the inverse correlation is that the ***ESI covers a wider range of sustainability issues than the Ecological Footprint*** including Environmental Systems, and Socio-institutional Capacity indicators, as well as measures of International Environmental Collaboration and Stewardship.
- High levels of resource consumption are clearly not sustainable over the long-term. However, countries with small footprints are not necessarily sustainable either. If their footprints are small because of a lack of economic activity and pervasive poverty, their situation cannot be held out as a policy aspiration.

Income Inequality Indices

Gini Co-efficient and Palma Ratio

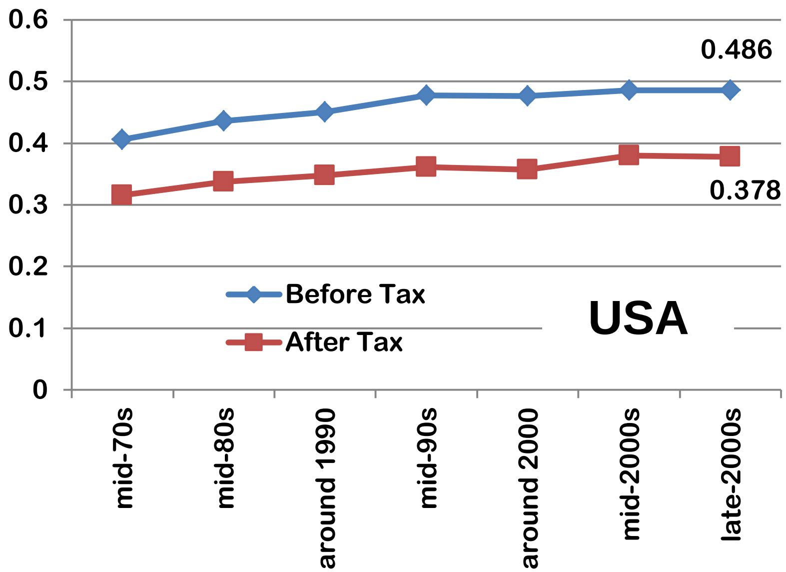
Gini Coefficient

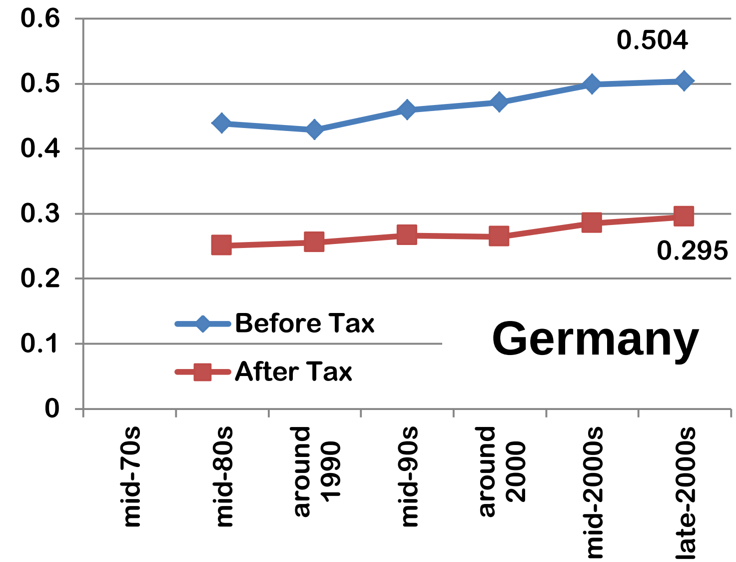


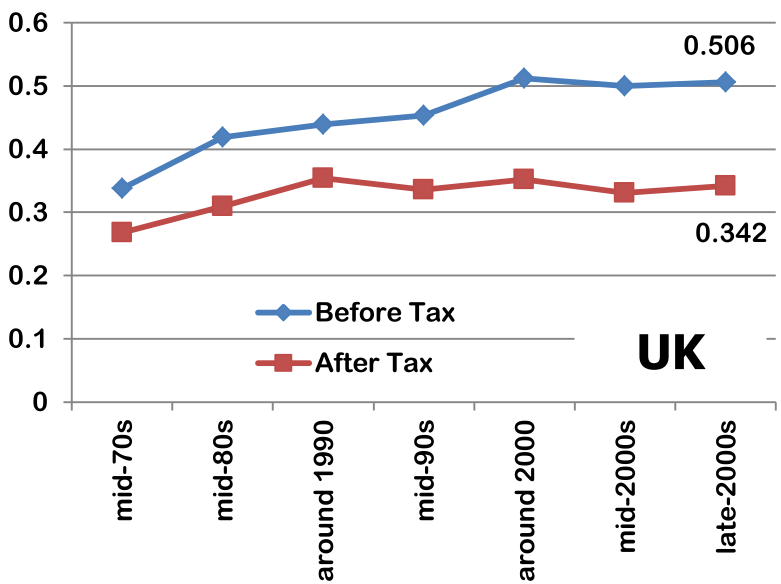
- The Gini coefficient measures the inequality among values of a frequency distribution (for example levels of income).
- A Gini coefficient of zero expresses perfect equality where all values are the same (for example, where everyone has an exactly equal income).
- A Gini coefficient of one (100 on the percentile scale) expresses maximal inequality among values (for example where only one person has all the income).
- The global income inequality Gini coefficient in 2005, for all human beings taken together, has been estimated to be between 0.61 and 0.68 by various sources.

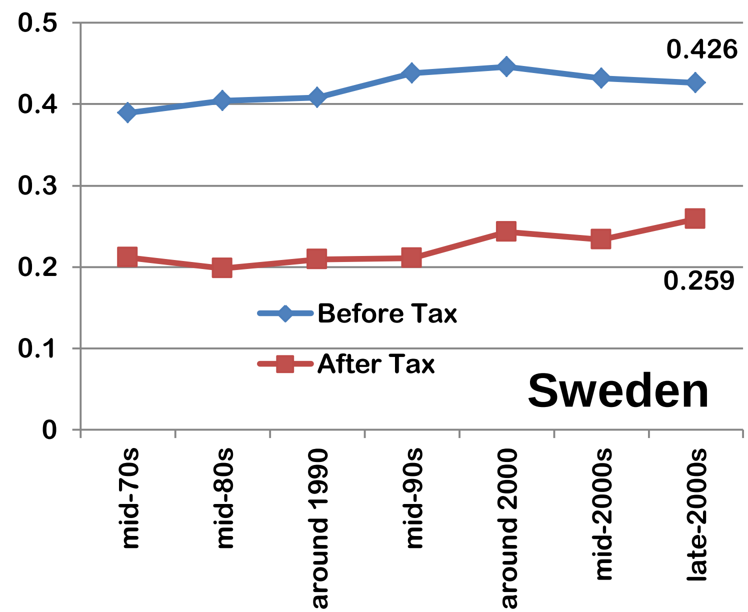
The Gini index is defined as a ratio of the areas on the Lorenz curve diagram. If the area between the line of perfect equality and the Lorenz curve is A, and the area under the Lorenz curve is B, then the Gini index is $A / (A + B)$. Since $A + B = 0.5$, the Gini index, $G = 2A = 1 - 2B$.

Gini Coefficients for a few countries









Gini Coefficient

Explanation:

I. The Gini coefficient can range from 0 to 1; it is sometimes multiplied by 100 to range between 0 and 100. A low Gini coefficient indicates a more equal distribution, with 0 corresponding to complete equality, while higher Gini coefficients indicate more unequal distribution, with 1 corresponding to complete inequality. To be validly computed, no negative goods can be distributed. Thus, if the Gini coefficient is being used to describe household income inequality, then no household can have a negative income. When used as a measure of income inequality, the most unequal society will be one in which a single person receives 100% of the total income and the remaining people receive none (G=1); and the most equal society will be one in which every person receives the same income (G=0).

II. It is mathematically equivalent to regard the Gini coefficient as half of the relative mean difference. The mean difference is the average absolute difference between two items selected randomly from a population, and the relative mean difference is the mean difference divided by the average, to normalize for scale.

Palma Ratio

- **Palma ratio divides the income share of the top 10% of the population by the income share of the bottom 40%.**
- **In countries with relative income equality this ratio is around one indicating that people in the top 10% on average earn four times the income of people in the bottom 40%.**
- In more unequal societies, the ratio is higher (e.g., 7 in South Africa and 4.8 in Bolivia).
- The strength of the Palma ratio is that it directly communicates the income distribution between poor and rich.
- However, it evens out the internal differences in the two groups.

Indicator of reduced national income inequality: Halving the part of the Palma ratio that exceeds one in 2030 compared to 2010

Selected country examples with year of data collection

Country	*Palma ratio 2010 Baseline (x)*	*Palma ratio 2030 Target (y=x-(x-1)/2)*
Bolivia (2008)	4.847	2.924
Brazil (2009)	4.302	2.651
Bulgaria (2007)	0.997	-
Burkina Faso (2009)	1.859	1.430
China (2005)	2.154	1.577
Denmark (1997)	0.922	-
France (1995)	1.267	1.134
Germany (2000)	0.992	-
Ghana (2005)	2.172	1.586
India (2004)	1.355	1.178
Japan (1993)	0.875	-
Malaysia (2009)	2.627	1.814
Netherlands (1999)	1.094	1.047
South Africa (2008)	7.052	4.026
Tanzania (2007)	1.653	1.327
United Kingdom (1999)	1.623	1.312
United States (2000)	1.852	1.426

The data available to calculate the baseline (the Palma ratio 2010) differ much in actuality and quality. Thus, the Palma ratio 2030 target figures are only tentative.

Source: Cobham and Sumner, 2013, and Index Mundi/the Luxembourg Income Study database.

Income shares in different countries, 2010