GE1040 A Culture of Sustainability

AY 25/26 Sem 1 — github/omgeta

1. Unsustainable Development

Unsustainable development harms the ability of future generations to meet their needs due to the degradation of our climate, life-support systems and resources.

i. Global Environmental Indicators: Planetary boundaries have already been exceeded (climate change, biodiversity loss, nitrogen cycle).
ii. Stability Landscape: Ecosystems may lose resilience — once thresholds are crossed (valley basins), systems may not return to their original state.
iii. Changing Climate: We are living in a changing climate. We need to mitigate impacts on us and ecosystem, or otherwise become more adaptable

Ecological Footprint

Terminology:

i. Bioproductivity: amount and rate of production occuring in an ecosystem over a period of time.
ii. Biocapacity = Area × Biocapacity: quantifies nature's capacity to produce renewable resources, provide land for built-up areas and provide waste absorption services such as carbon uptake.
iii. Ecological Footprint (gha) = Population × Consumption/Person × Footprint Intensity: quantifies biological productive area needed for provision of renewable resources, or require absorption of CO_2 waste.
iv. Footprint and biocapacity can be ranked by countries, enabling them to learn from each other.
v. Ecological Deficit: ecological footprint>biocapacity (currently exceeded by 50%).

Earth Overshoot Day is the date when annual footprint exceeds annual biocapacity:

i. Occurs earlier each year (first at 1970)
ii. COVID-19 caused ecological footprint to contract
iii. #MoveTheDate: push overshoot to December via sustainable cities, resilient systems, etc.

Causes

Overpopulation due to exponential population growth:

i. 8.1b (2025) → 9.5b (2050) → 11b (2100)
ii. Pressure on land, soil degredation, and biodiversity
iii. Prior to Industrial Revolution, growth was resource-limited but now largely unchecked
iv. Various demands by billions for a comfortable life, but everyone should have the equal right to health

Unsustainable Resource Use:

i. Affluenza: oversumption in affluent societies
ii. Developing countries fixated on GDP as sole success metric ignoring environmental costs

Poverty links to environment in a downward spiral:

i. Direct reliance on food, water, fuel for survival
ii. Degenerate forests, soil, grasslands and wildlife causing environmental degradation
iii. Degraded environment further impoverishes people

Excluding Environmental Costs:

i. Market prices ignore externalities such as ecosystem loss, health impacts and pollution
ii. Ex. Timber companies pay to clear forests but not for environmental degradation and loss of habitat
iii. Ex. Fishing companies pay to catch fish but not for depletion of fish stocks
iv. Taxes and fines aim to fix this but not enough

Tragedy of the Commons

Tragedy of the commons is the overuse of a common property or free-access resource causing depletion for all.

i. Mentality of "If I do not use it, someone else will. The little bit I use or pollute doesn't matter".
ii. Solutions:
   - Responsible usage of shared renewed resources at rates well below sustainable yields
   - Convert open-access renewable resources to private ownership

IPAT Model

IPAT quantifies environmental impact as $I = P \times A \times T$ where P is population, A is affluence, T is technology:

i. Population: not dominant factor
ii. Affluence: $\frac{\text{Goods \& Services}}{\text{Person}}$ can harm through high consumption, pollution and resource wastage but also produce funding for innovative R&D (e.g. Denmark, India's ethanol-blended gasoline)
iii. Technology: $\frac{\text{Impact}}{\text{Goods \& Services}}$ reduces impact
iv. Ex.: Gasoline = cars × miles/car × gasoline/mile

Pollution

Pollution is the introduction of contaminants into the natural environment that adversely affects a resource.

i. Point Source: single, identifiable source (e.g. smokestack, drainpipes)
ii. Nonpoint Source: dispersed and difficult to identify (e.g. fertilizer and pesticide runoff into lakes - first flush effect after dryspell)

Health Effects:

i. Headache and Fatigue
ii. Respiratory Illness
iii. Cardiovascular Illness
iv. Cancer Risk
v. Nausea and Gastroenteritis
vi. Skin Irritation

Management Methods:

i. Cleanup (end-of-pipe): clean/dilute contaminants
   - Temporary; growth in consumption may offset pollution control tech
   - Often relocates pollutants to another area
   - Costly to clean dispersed pollutants
ii. Prevention (front-of-pipe): reduce/stop production

Environmental Viewpoints

Planetary Management:

i. View: We are apart from the rest of nature and can manage it to meet our increasing demands.
ii. Resources: We will not run out, due to our ingenuity and technology.
iii. Economy: Potential for economic growth is essentially unlimited.
iv. Success: Depends on how well we manage the earth's life-support systems for our benefit.

Stewardship:

i. View: We have an ethical responsibility to be caring stewards of the earth.
ii. Resources: We will probably not run out, but they should not be wasted.
iii. Economy: Encourage environmentally friendly economic growth and discourage harmful forms.
iv. Success: Depends on our managing the earth's life-support systems for our and nature's benefit.

Environmental Wisdom:

i. View: We are part of and totally dependent on nature, and nature exists for all species.
ii. Resources: Limited and should not be wasted.
iii. Economy: Encourage earth-sustaining economic growth and discourage earth-degrading forms.
iv. Success: Depends on learning how nature sustains itself, integrating them into how we think and act.

2. Principles and Practical Applications of Sustainability

Environmentally sustainable societies meet present needs without compromising future generations' own needs:

i. Without destroying the environment
ii. Without endangering the future welfare of the planet and its people
iii. In a just and equitable manner

Sustainability is the ability of Earth's natural systems, cultural systems and economies to survive and adapt to changing environmental conditions indefinitely. 3 Pillars:

i. Environment (ecological integrity)
ii. Economy (economic viability)
iii. Society (equity)

Sustainable Development Goals (SDGs)

UN Sustainable Development Goals (SDGs) were adopted in 2015 by 2500 scientists from 190 nations, providing a global framework to steer towards a safe and just operating space for society to thrive in until 2030:

1. No Poverty
2. Zero Hunger
3. Good Health and Well-being
4. Quality Education
5. Gender Equality
6. Clean Water and Sanitation
7. Affordable and Clean Energy
8. Decent Work and Economic Growth
9. Industry, Innovation and Infrastructure
10. Reduce Inequality
11. Sustainable Cities and Communities
12. Responsible Consumption and Production
13. Climate Action
14. Life below Water
15. Life on Land
16. Peace and Justice Strong Institutions
17. Partnerships to achieve the Goal

International Spillovers

Spillovers are transboundary negative impacts generated by one country on others, which can undermine their ability to achieve the SDGs, measured by Spillover Score. Types of spillovers:

i. Environmental: use of natural resources and pollution, including transboundary effects embodied in trade, and direct cross-border flows in air and water
ii. Economic/Financial/Governance: international development finance, unfair tax competition, banking secrecy, and labor standards
iii. Security: negative externalities such as arms trade and organized crime destabilizing poorer countries; positive spillovers include conflict-prevention and peacekeeping investments

Natural Capital

Natural capital (natural resources + natural services) refers to the stock of natural resources and ecosystem services that sustain human life :

i. Natural Resources: includes air, water, soil, land, life (biodiversity), nonrenewable resources, renewable energy and nonrenewable energy
ii. Natural Services: includes air purification, water purification, water storage, soil renewal, nutrient recycling, food production, conservation of biodiversity, wildlife habitat, forest renewal, waste treatment, climate control, population control and pest control
iii. Degradation of natural capital undermines long-term sustainability
iv. Preserving natural capital is essential for intergenerational equity

Sustainability Concepts

Shifting Emphasis:

i. Pollution cleanup → Pollution prevention
ii. Waste disposal → Waste prevention and reduction
iii. Species protection → Habitat protection
iv. Environ. degradation → Environ. restoration
v. Increased resource use → Less wasteful resource use
vi. Population growth → Population stabilization by decreasing birth rates
vii. Depleting and degrading natural capital → Protecting natural capital, living off bio-interest

Lessons from Nature:

i. Runs on renewable solar energy → Rely mostly on renewable solar energy
ii. Recycles nutrients and wastes (little waste) → Prevent/reduce pollution, recycle & reuse resources
iii. Uses biodiversity to maintain and adapt to environmental change → Preserve biodiversity by protecting ecosystem services, habitats and species
iv. Controls species' population size and resource use → Reduce births and wasteful resource use to prevent environmental overload, and depletion and degradation of resources

Challenges:

i. Depletion of finite resources (fossil fuels, soil, minerals, species)
ii. Overuse of renewable resources (forests, fish & wildlife, soil fertility, public funds)
iii. Pollution (air, water, soil)
iv. Inequity (economic, political, social, gender)
v. Species loss (endangered species and spaces)

Solutions:

i. Cyclical use of resources (emulate nature; 3R's)
ii. Safe reliable energy (conservation, renewable energy, subtitution, interim measures)
iii. Human well-being interests (health, creativity, learning, cultural and spiritual development)

Research & Development (R&D)

Examples of sustainability-oriented research and indigenous technology development:

i. Power Generation: Biogas integrated with waste management/Co-Gen systems
ii. Construction Materials: Local, non-toxic, reusable materials; water as material for thermal walls
iii. Water Supply: Rainwater harvesting for groundwater recharge and building cooling
iv. Water Treatment: Natural biomaterials for turbidity removal; UV disinfection from sunlight; fabric filtration for point-of-use treatment
v. Storm-water Management: Green roofs for runoff reduction, reduced energy use, and cooling effect
vi. Building Design: Passive solar design, right-sized homes, cost-effective ventilation, maximize storage and comfort with minimal energy

Green Roofs are intensive (thick substrate, shrubs/trees) or extensive (thin substrate, smaller plants):

i. Aesthetically pleasing
ii. Reduce storm-water runoff
iii. Reduce urban heat island effects
iv. Reduce air conditioning costs
v. Negate acid rain effects
vi. Reduce CO_2 impact
vii. Create habitats for certain plants and animals
viii. Cooling Effect: protects from solar radiation, stabilizes roof temperature, cools building interiors
ix. Water Quality: depends on substrate layer, vegetation type, fertilisation quality, roof age, surrounding area type, local pollution sources

Key Carbon Considerations:

i. Embodied: emissions from construction materials
ii. Operational: emissions from running processes

Case Study: NUS Sustainability Initiative

Current Practices:

i. Integrated into education, research, campus operations, and leadership
ii. Contributes directly to multiple SDGs such as climate action, clean energy, and sustainable cities

Future:

i. Driving sustainability via collaboration with other sectors (internal and external partners)
ii. Building climate resilience by linking research across climate, urban, economic, and social areas

Case Study: Punggol Digital District (PDD)

Current Practices:

i. 17 Green Mark Platinum and 3 Super Low Energy Buildings (e.g. Mass Engineered Timber with 98% lower embodied carbon)
ii. Smart Energy Grid: real-time data management optimisation saves 1,700 tonnes CO_2 annually; rooftop PV panels generate 3,000 MWh annually
iii. Open Digital Platform (ODP): collect and analyse environmental and building data to improve energy efficiency, reduce costs and minimise impact
iv. Digital Twin: real-time planning-simulation model
v. Centralised Cooling System: cooling towers with underground distribution reduce energy use by 30% and 3,700–4,000 tonnes CO_2 annually
vi. Carlite District: prioritises low-emission transport

Future:

i. Environmental Modelling
ii. Use of recycled materials for construction
iii. Fuel Cell System for Lifts
iv. Regenerative Lift converts motions into energy
v. Centralized Chutes for Recyclables
vi. "Develop an eco-town with a human settlement that enables its residents to live a good quality of life while using minimal natural resources."

3. Circular Economy

Circular economy is a regenerative system where resource input, waste, emissions, and energy leakage are minimised by slowing, closing, and narrowing resource loops.

i. Replaces the end-of-life concept with long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling
ii. Regenerate natural systems by returning valuable nutrients to ecosystems
iii. Supports economic, environmental, and social dimensions of sustainable development
iv. Mimics nature's cyclical systems

Economy Progression:

i. Linear Economy: take → make → dispose (single-use, wasteful)
ii. Recycling Economy: partial recovery through recycling but still wasteful
iii. Circular Economy: design for closed loops, resources kept in circulation, waste designed out

Energy and Matter

High-quality energy is concentrated, good for useful work. Low-quality energy is dispersed, bad for useful work.

Three Big Ideas:

i. There is no "away": matter cannot be destroyed, only converted (Law of Conservation)
ii. Cannot get something for nothing; cannot get out more energy than in (1st Law of Thermodynamics)
iii. Cannot break even; energy conversion from one form to another reduces energy quality or less usable energy (2nd Law of Thermodynamics)

Economy Types:

i. High-throughput economy: unsustainable, high-waste, promotes pollution
ii. Low-throughput economy: matter-recycling and reuse; mimics nature and reduces pollutants but may be insufficient for growing populations

Industrial Symbiosis

Industrial symbiosis is a business relationship focused on sharing resources between industrial facilities/companies where wastes or byproducts from one become raw materials for another.

i. Subset of Industrial Ecology: shift from linear to cyclical (closed-loop) systems
ii. Mutually beneficial cooperation which reduces environmental impact while improving business competitiveness
iii. Key enabling business model for advancing the move to a circular economy
iv. Ex. Kalundborg, Denmark: cooperation among 8 industries sharing energy, water, and materials

Applications and Innovations

i. Bioplastics: key enabler of low-carbon circular economy; allow closed resource cycles and cascading reuse especially when being reused or recycled
ii. Design for longevity: durability, easy repair, remanufacturing
iii. Closed resource cycles: minimize virgin resource extraction via reuse and recovery
iv. Resource Recovery: convert waste streams into valuable resources (e.g., waste-to-energy, nutrient recovery, material cascading)

4. Sustainable Urbanisation

Case Study: Stockholm

Case Study: Singapore

5. **Sustainable Infrastructure**
6. **Air Quality**
7. **Climate Change**
8. **Nonrenewable Energy**
9. **Renewable Energy**
10. **Sustainable Water Resources**
11. **Zero Waste**
12. **Environmental Hazards and Health**