Summary: Sustainable Engineering

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PART 1 Introduction and Motivation

1 The basis of human well being

1.1 Trends in Human Development

- Population growth indication of success. 7.2 billion to 9.6 – 12.3 billion by 2100.
- GDP: Monetary value of all goods and services produced.
- HDI: Combined factors such as health and education with income. 3 factors, life expectancy at birth, mean of years of schooling by 25, and a logarithm of income. Does not reflect inequality, poverty.
- Boom in population with exponential growth starting in the 1800s. GDP follows this growth.
- GNI: Gross national income, per capita
- Both child mortality rates and proportion of people living on less that 1.25 decreased drastically since 1990.
- Sub-Saharan Africa worst, then southern Asia, northern Africa doing decent.

1.2 What does human well-being depend on?

- Economic goods and services: equipment, energy supply, market for products, industrial waste treatment, food, and transportation. Monetary.
- Societal goods and services: labor, education, intellectual capita, legal system, government, and culture. Both monetary and not.
- Ecological goods and services: nature, minerals, water, air, sunlight. Not monetary.
- Societal and economic goods depend on ecosystems.
- Human development in replacing ecosystem: climate-controlled buildings and genetically modified crops.
- Biosphere 1: planet earth, no substitute currently.

1.3 Ecosystem goods and services

- Humans derive from nature, natural capita and fundamental for human activity
- Natural resources, minerals, soul, forests

- If emissions exceed the ability of nature to absorb and mitigate them, then human and ecological systems may suffer damage and lose their ability to provide various services.
- Provisioning services: products from ecosystems: food, fresh water, fuel, biochemicals.
- Regulation and maintenance services: benefits from maintenance of ecological processes by the regulation of air quality, water quality, climate, diseases.
- Cultural services: nonmaterial benefits like spiritual and religious values, cultural diversity and education and aesthetic values.

1.4 What about saving the planet?

- Saving the planet is not the ultimate goal of sustainable engineering, human well-being is.
- Human well-being is dependent on healthy ecosystems, sustaining ourselves does require saving the planet.

1.5 Summary

- Human well-being has improved over the last centuries (GDP, HDI).
- Due to utilizing goods and services for economic, societal and ecological systems.
- Goods and services from nature are provisioning, regulating and cultural.

2 Status of ecosystem goods and services

- Three forms of wealth, material, cultural and biological

2.1 Fuels

- Nonrenewable fossil fuels depletion
- Peak in price inevitable
- Availability but also regulation

2.2 Materials

- Mobilization from human activities larger than natural mobilization for some materials
- We have synthesized over 50 000 molecules in the last few decades

2.3 Water

- Most used for growing food
- High water use is increasing water stress, disruption in water availability
- Disruption in rivers
- Habitat destruction, animal migration pattern disruption, and human resettlement have negative societal side effects.

2.4 Food

- There is enough food available for everyone on the planet
- Scarcities due to challenges in food distribution and purchasing power, not production
- Industrial farming has had its side effects, a role in the degradation of ecosystem services

2.5 Soil

- Food production
- Most of earth movement happened in the last several decades
- Soils degraded due to intensive farming

2.6 Air Quality Regulation

- An emission becomes a pollutant when its concentration exceeds natures capacity to use or capture it

2.7 Climate regulation

- Trend implies that emission of carbon dioxide greatly exceeds the capacity of nature to capture it through processes such as photosynthesis

2.8 Water quality regulation

- Wetlands are being lost (swamps), they are important for regulating water quality
- Converting atmospheric nitrogen into reactive nitrogen $N_2 + 3H_2 \rightarrow 2NH_3$ food production keeping up with population growth.

2.9 Net Primary Productivity

- Increasing population and per capita consumption, people have been appropriating a larger fraction of the planets NPP.
- Transforming Earths' surface for use through agriculture and urbanization
- NPP on Earth has an upper limit

2.10 Pollination

- Provide a service that enhances the production and nutritional content of foods.
- Estimated value of 215 billion USD in 2005.
- Population of pollinators declining.

2.11 Biodiversity

- Diversity essential for maintaining Earths resilience and ability to provide goods and services.
- 5 mass extinctions so far, in the middle of a 6th, previous event was the dinosaurs.
- Rate of extinction is 1000 times greater than the natural rate.

2.12 Overall status

- 24 ecosystems. 15 degraded, 5 mixed, 4 enhanced.
- Biodiversity loss significantly above the safe limit, same with disruption of nitrogen and phosphorus cycles.
- Anthropocene epoch, or "age of man".

2.13 Summary

- Large number of essential ecosystem services are degrading or declining.
- Pressure imposed by human activities.

3 Sustainability: Definitions and challenges

- Can human well-being be maintained and enhanced by the approaches we have adopted.

3.1 Definitions

- Brundtland commission: Meets the needs of the present without compromising the ability of future generations to meet their own needs.
- Sustainability is anthropocentric: its focus is primarily on human well-being.
- Sustainable development is about the present and the future: it emphasizes the short- and long-term aspects of satisfying human needs.
- Nature plays an essential role in sustaining human activities.
- Limits on the sustainability of human activities are imposed by the ability of ecosystems to provide resources and absorb impacts.
- Difficult to determine the needs of future generations, and ecological capabilities for supporting human activities.

3.2 Nature of environmental problems

- Wood replaced by coal, domestic coal replaced by imported coal.
- More efficient oil extraction
- Urbanization continues and demands more fresh water, rivers are diverted and dams are built.
- Human adaptation and ingenuity in exploiting new resources and developing more efficient technologies.
- 3.2.1 Energy-efficient lighting: even though more efficient, consumption still increasing
- 3.2.2 Sustainable transportation: Horses were problematic. Cars introduced; they caused their own environmental problems.
- *Shifting of impacts along the supply chain*: new solutions may just impact where in the supply chain the damage is done.
- *Shifting of impact to other geographic regions*: Regional restrictions may just change where environmental impact if done.
- *Shifting of impact across disciplines*: Greater use of corn-based ethanol increased the demand for corn, jump in prices for products made from corn.
- *Shifting of impacts between types of flows:* Biofuel may decrease carbon dioxide emissions but utilizes more land.
- *Ignoring supply and demand of ecosystem goods and services:* technological enhancements prioritized over demands on ecosystems.

3.3 Nature of sustainability challenges

- 3.3.1 Need for sustainable engineering. Today's engineering is based on assumptions from years ago when ecosystem goods where plenty.
- Biosphere is under significant pressure
- The impact of human activities is increasing, production of economic goods is going up

- Engineering is therefore crucial for developing sustainable solutions, but it faces thermodynamic limits
- 3.3.2 Wicked nature of sustainability. Consider temporal, spatial and disciplinary aspects, and interactions with ecological and economic systems, in decisions for sustainable development.
- Difficult to know if a system truly is sustainable. Interaction between the large number of subsystems makes the overall system complex and difficult to understand and predict.
- “Wicked” not easy to define the end goal of sustainability, therefore many different definitions.
- Collapse, may conclude not sustainable. While persisting, may not conclude.

3.4 Requirement for sustainability

- Science and engineering have developed by dividing disciplines into specializations and by focusing on them to gain insight that often result in new technologies and solutions.
- Ecosystems often undervalued, leading to assumptions that nature is limited.
- Operate within ecological limits
- Be acceptable in society
- Contribute to economic prosperity
- Sustainable systems must not demand more from ecosystems than can be supplied without transgressing critical thresholds.
- Account for the demand of ecosystem goods and services.
- Account for the supply of ecosystem goods and services.
- Consider multiple spatial scales. (Life cycle).
- Consider temporal interactions.
- Consider cross-disciplinary effect.
- Consider multiple flows.

3.5 Approaches toward sustainable engineering

- Enhance efficiency.
- Use renewable resources.
- Emulate nature.
- Adaptive management.

3.6 Summary

- Impact may shift across temporal, spatial, and disciplinary boundaries, and between types of flows.
- Therefore, we cannot react sustainability from one single discipline (sustainable engineering is born).

PART 2 Reasons for Unsustainability

4 Economics and the Environment

5 Business and the environment

5.1 Pre-1980s: Environmental Protection as a Threat

- Mining and refining activities were among the early causes of soil contamination.
- Exporting waste to developing countries was common.
- Air pollution (Clean Air Act of 1956)
- Cultural, Londoners defended coal-burning as their birthright and sign of freedom.
- Attitude, beyond the amount that is in the best interest of the corporation or that is required by law.

5.2 Post-1980: Environmental Protection as an Opportunity

- Increasing public pressure and change in perception due to clear evidence of negative impacts.
- CFC Ozone hole
- Resource efficiency by reducing pollution and new innovation by policies.
- 3Ms 3P Program to prevent pollution rather than treat it
- Must eliminate or reduce a current or potential pollutant
- Project must reduce the use of energy or raw materials
- Involve technical solutions or innovation
- Project should be monetarily attractive
- Cost of environmental protection may be eliminated by innovation
- Innovation may not necessarily enhance sustainability
- Environmental protection necessary to being competitive.
- Greenwashing: giving a false impression of sustainability

5.4 The future of corporate sustainability, by Joseph Fiksel

- Diminishing returns for resource efficiency
- Capacity to adapt continuously, enterprise resilience
- Decreasing waste increases economic efficiency, which results in more goods and services being consumed: Rebound effect
- Businesses thrive in a flourishing society that drives improved and equitable human well-being
- The well-being of human societies, including health, prosperity and dignity, depends upon a continued balance of natural, economic, and social capital.
- While some progress has been made, greater truest and collaboration among industry, civil society, and government is essential to understanding this balance and driving further progress
- *Embracing transformational change*
- *Data-driven decision making*
- *Collaborating at scale*
- *Enabling public policy solutions*
- *Influencing consumer behavior*
- *Extreme transparency*
- *Educating the next generation*

5.5 Summary

- Environmental: Unnecessary -> Necessary evil -> Source of business advantage

6 Science, engineering, and the environment

6.1 The Attitude

- Engineering and scientific advantage responsible for substantial environmental harm
- Modern science has developed with an attitude of dominating nature and improving upon it, modern engineering is the way of making this happen.
- Controlling flow and availability of water, (dams and canals).
- Genetically modified crops.
- Haber-Bosch process. Commercial nitrogen fixation.
- Attitude has taken nature for granted and assumption that technology can always be developed to solve problems like the deterioration of ecosystems.
- Low literacy in ecology among engineers and scientists.

6.2 The Approach

- 6.2.1 Reductionism: Specialized to consider smaller components of a system. The whole is equal to the sum of its parts.
- Encourages very narrow specialization, and a lack of ability to see the big picture, that is necessary to reducing the change of unintended consequences.
- 6.2.2 Holism: Addressing the shortcoming of reductionist thinking, whole by understanding interaction and links between components.
- Design and operate manufacturing processes.
- Reductionist design, maximizing reactor conversion. Holistic design, account for the presence of recycle loops and permit reuse of reactants.
- Holistic approach for gene modification, considers result of development of Bt-cotton, and its effects other than just increasing yield of cotton or reducing the use of pesticides.

6.3 The Outcome

- Unsustainable outcome often justified or encouraged by businesses and governments to satisfy economic objectives.
- Technology that solves a problem often shielded by large governments.
- People find out, public relations efforts attempt to deflect questions.
- Negative side effects become better known, try to hide the use of the technology.

6.4 Summary

- Attitude of being better than natura, combined with the approach of reductionism are key factors that have contributed to unsustainable technological developments.

7 Society and the Environment

7.1 Cultural Narrative

- No matter how useful a technology or policy, if society does not adopt it then it will have little to no effect.
- Attitude and behavior of a group of people. Determines society's impact on the environment and its willingness to accept and respond to these impacts.

- Dominant cultural narrative across the world revolves around economic growth and consumption of material goods, without being too concerned about the negative side-effects of these activities.
- Awareness about ecological degradation has been increasing.
- Reasons for cultural narrative: market force to provide feedback to society about harm. Absence of an appropriate moral compass. Apathy or ignorance exemplified by the thinking that environmental impact is inevitable.
- Follows society at large
- Techno optimism, technology will be available to solve problems relating to unsustainability of human activities.
- People are ignoring warnings and other efforts, even though they are based on research (goes against the cultural narrative).
- Need to change the cultural narrative to get people on-board.

7.2 Ecological Literacy

- Scientific knowledge about nature has increased, but this is restricted to specialists.
- In the general public, many studies indicate is declining.

7.3 Political Aspects

- Some people benefit from keeping the status quo

7.4 Ethics, morals, and religion

- Modern philosophy developed while taking nature for granted.
- Ethics and moral principles on how to treat nature are recent or rediscovered.
- Anthropocentrism: Humans are separate to and better than nature.
- Strip nature of any sacrality.
- Technology identified with religious virtue
- Nonhuman as relative rejected
- Wilderness cursed land
- Promised land is opposite earth
- Older eastern religions nature is more central

7.5 Summary

- Societal aspects arguably the most important factor to determine the sustainability of human activities.

PART 3 Sustainability Assessment

19 Industrial Symbiosis and the Circular Economy

- Nature as model mean imitating or being inspired by the way nature does things to meet human needs
- Nature as mentor considers nature as a way of judging the appropriateness of human activities, using the argument that since nature has been around for so long, it has figured out what is right and what works.
- Nature as measure implies that our focus should be on learning from nature and not just extracting from it.

19.1 Biomimetic Product Innovation

- Mimicking nature is a successful and active area of research and innovation.
- Materials: Velcro inspired by bars
- Movement: fast trains based on kingfisher's beak.
- Function and behavior: self-cleaning surfaces based on the structure of lotus leaves.
- Sensors: developed by mimicking nature including radar-based bat navigation.
- Will not necessarily take us closer to sustainability (rely on non-sustainable materials, Velcro from plastic).

19.1 Industrial Symbiosis

- The goal of industrial symbiosis is to establish a network of industrial processes in which waste from one process is used as a resource in another.
- Mimic ecological systems and their self-sustaining nature.
- Trade waste that would otherwise be discarded.
- Attracts new industries in niche areas to provide a broader economic benefit.
- Industrial symbiosis requires trust between businesses.
- Waste is usually less consistent in quality.
- Information about the supply and demand of wastes are not readily available.
- Symbiosis results in greater interdependence between businesses.

19.2 The Circular Economy

- The concept of circular economy focuses on closing loops for products and materials.
- Encourages reuse and extended use by remanufacturing and repair and keeping materials in the economy by recycling and recovery.
- Resources that are lost during manufacturing may be kept in the economy by using them in other industries by industrial symbiosis.
- Linear economy: Materials used once then discarded.
- Circular economy: Materials are reprocessed.
- Performance economy: Emphasizes the service provided rather than the product. Easier to close material loops.
- DPM (Domestically Processed Material): Quantity of domestic consumption and recycling. Includes imports but not exports.
- DPO (Domestically Processed Output): All the material output produced in the system.
- Stock growth is the fraction of DPM that contributes to the net addition of stock.
- Degree of circularity is the fraction of DPM that is recycled.
- Biodegradable flow is the fraction of DPM that is biodegradable.

- Throughout is the fraction of DPM that form DPO.

19.3 Summary

- Learning from nature is attractive as a source of potential solutions for sustainability.
- Simply mimicking nature in a reductionist manner is not enough for sustainability.

21 Industrial Symbiosis and the Circular Economy

- The external social cost of economic activities is not included in the price. This can result in excessive resource use and tragedies of the commons.
- Discounting gives less importance to the future. This makes it difficult to justify decisions with long-term benefits.
- Perfect sustainability is assumed between natural and economic capital. This could downplay ecological degradation by assuming that economic capital can act as a substitute for lost natural capital.
- The physical basis of the economy is not fully considered. This mean that the role of the ecosystem services in supporting the economy is undervalued or ignored.

21.1 Internalizing Externalities

- The environment is kept outside the market boundary, resulting in negative environmental externalities.
- 21.1.1 Non-Market-Based Policies: Government regulation like banning pollutants. Best available technology and acceptable pollution level.
- Specifying the technology can stifle innovation towards the development of better technologies and other solutions.
- Determining the acceptable pollution level to include in the regulations was not easy.
- Regulation tends to be a source of conflict between industry and government.
- 21.1.2 Market-Based Policies. Environmental taxes.
- Pigouvian tax, damage due to displacement, emissions. These external social costs get a monetary value.
- Tradable emissions permits: combines regulation, environmental taxes, and property rights.
- Quota for maximum allowable amount of pollution or resource use which is distributed among stakeholders.
- Interested parties trading by selling or buying these permits, for example if buying permits is cheaper than reducing emissions.
- Payment for ecosystem services: Monetizing ecosystem services and developing trading schemes to create a market for them. Help alleviate poverty, since many poor people work close to the land in occupations such as farming, fishing and forestry.
- Risks are loss of the right to harvest products, increased competition, and incompatibility with cultural values.

21.2 Inclusive Wealth

- Inclusive wealth is an approach that measures the wealth of nations by carrying out a comprehensive analysis of a countries productive base.

- Manufactured capital: industry
- Human capital: education and health
- Natural capital: resources
- Shadowing prices are meant to capture preferences that people have for goods and services.
- Africa: decreased due to increase in population and decrease in natural capital per capita
- Asia: lost natural capita per person, but increase in manufactured capital more then compensate for the loss
- North America: Same as Asia basically
- This data can be used to developing appropriate economic policies.

21.2 Summary

- Creating markets for ecosystem goods and services has become one of the most popular approaches for internalizing economic externalities, and it allows markets to find the appropriate balance between the use of ecosystem goods and services and their protection.
- Inclusive wealth more complete metric than for example GDP and HDI, and gives insight into trends in manufacturing, human, and natural capitals.