Environmental Engineering

LIU Yang

Content

Introductiony

Chapter 1: Introduction to Environmental Engineering and Problem Solving;
Chapter 2: Essential Chemistry Concepts

Other Pollution

Chapter 8: Municipal Solid Waste Management
Chapter 9: Air Pollution

Water Treatment

Chapter 3: Water and Wastewater Characteristics
Chapter 4: Essential Biology Concepts
Chapter 5: Modeling and Reactor Design
Chapter 6: Design of Water Treatment Systems
Chapter7:Design of Wastewater Treatment Systems

Management

Chapter 10: Environmental sustainability
Chapter 11: Environmental Public Health
Chapter 12: Hazardous Waste Management

Chapter 10 Environmental sustainability

Learning Objectives

- explain the causes and consequences of global climate change;
- describe the environmental effects of rapid human development;
- estimate ecological footprints;
- evaluate the potential for use of different forms of renewable energy;
- understand the use of indicators of human development that include economic output, sustainability and well-being.

Chapter 10 Environmental sustainability

10.1 Overview

- Concern for the environment, and a realization that humanity needs to develop in a sustainable way, is not new.
- In 1919, Svante Arrhenius, the Director of the Nobel Institute, wrote (Arrhenius, 1926):

"Engineers must design more efficient internal combustion engines capable of running on alternative fuels such as alcohol, and new research into battery power should be undertaken... Wind motors and solar engines hold great promise and would reduce the level of CO2 emissions.

Forests must be planted... To conserve coal, half a tonne of which is burned in transporting the other half tonne to market... The building of power plants should be in close proximity to the mines ... All lighting with petroleum prod ucts should be replaced with more efficient electric lamps."

Chapter 10 Environmental sustainability

10.1 Overview

- On November 28, 2024, the last section of the Taklamakan Desert's edge was successfully "locked", marking the completion of a 3046-kilometer green sand barrier around the desert. This is the world's longest ecological barrier around a desert.

——China Daily

Chapter 10 Environmental sustainability

10.1 Overview

- Sustainable Developmen—— "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

—— The Brundtland Report, also known as "Our Common Future"

- The report highlighted three fundamental components of sustainable development: environmental protection, economic growth and social equity.

1 Renewable resources such as fish, soil, and groundwater must be used no faster than the rate at which they regenerate (for example, fish are harvested unsustainably if heir rate of capture is greater than the rate of growth of the remaining population).

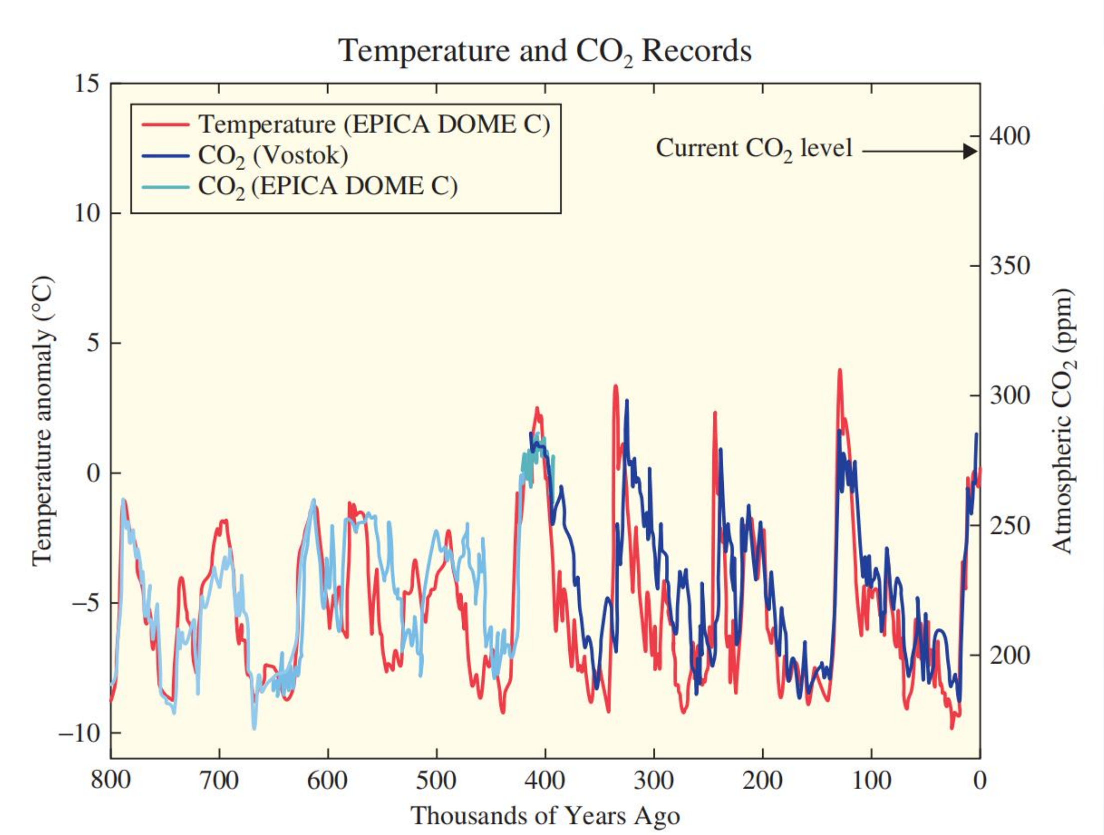
2 Nonrenewable resources such as minerals and fossil fuels must be used no faster than renewable substitutes for them can be put into place.

3 Pollution and wastes must be emitted no faster than natural systems can absorb them, recycle them, or render them harmless.

Chapter 10 Environmental sustainability

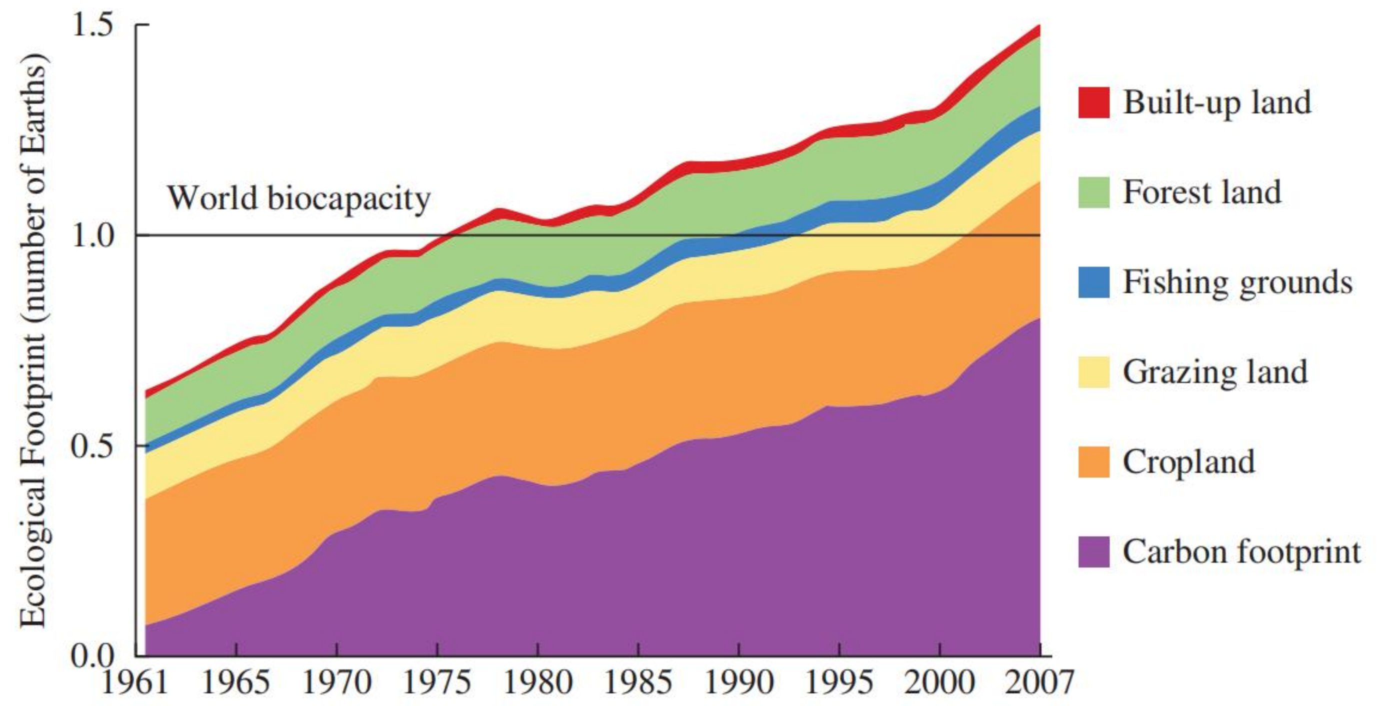
10.1 Overview

- Possibly the most pressing environmental issue is that of climate change. People have long suspected that human activity could change the local climate.
- The link between carbon dioxide and temperature is demonstrated using data from the Vostok ice cores,



10.1 Overview

- The Ecological Footprint (EF), first proposed by Wackernagel and Rees at the University of British Columbia (Rees, 1992), was developed to provide this knowledge, based on a global perspective. The Ecological Footprint measures the amount of land and water required to supply humanity with the resources it needs and to absorb its wastes.



10.1 Overview

- By 2007, using the EF as a measure, humanity was using the equivalent of 1.5 Earths. This is obviously not sustainable.
- Sustainable development can only be achieved if society, economics and the environment are all simultaneously taken into consideration.Since levels of carbon dioxide in the atmosphere are regarded as being primarily responsible for increasing temperatures, an obvious response would be for humanity to reduce emissions of this gas. Burning of fossil fuels is the major source of carbon dioxide emissions, so finding alternatives for these fuels is imperative.

10.2 Unsustainable earth

10.2.1 Climate change

- The factors used in describing climate include temperature, precipitation and wind. This system is powered by solar radiation.
- The almost constant variables affecting climate include latitude, altitude, proximity to oceans and mountains. In addition, slight changes in Earth's position and orientation relative to the Sun bring the Earth closer to the Sun and take it further away from the Sun in predictable cycles.
- Other factors affecting the climate are more dynamic. The thermohaline circulation 温盐循环of the ocean.Extent of ice and snow cover determines how much of the Sun's energy gets reflected back into the atmosphere, and the type and density of vegetation affects solar heat absorption, water retention保持, and rainfall. Alterations to the quantity of greenhouse gases emitted result in changes to the greenhouse effect.

10.2 Unsustainable earth

10.2.1 Climate change

10.2.1.1 Greenhouse Effect

- The greenhouse effect is a natural phenomenon that insulates the Earth from the cold of space. Without this greenhouse effect, the average temperature of the Earth would be approximately 30℃ cooler.
- External causes of change in the climate are known as drivers or forcings. These factors can be natural phenomena, such as volcanic eruptions, or human-induced change to the atmosphere, such as the release of greenhouse gases.

10.2 Unsustainable earth

10.2.1 Climate change

Table 10.1 The Global Warming Potential and atmospheric lifetimes of various greenhouse gases relative to CO_2.

Gas	Chemical Formula	Lifetime (years)	Global Warming Potential (GWP) 20-year period	100-year	500-year
Carbon dioxide	CO_2		1	1	1
Methane	CH_4	12	72	25	7.6
Nitrous oxide	N_2O	114	289	298	153
CFC-12	CCl_2F_2	100	11,000	10,900	5,200
HCFC-22	$CHClF_2$	12	5,160	1,810	549
Tetrafluoromethane	CF_4	50,000	5,210	7,390	11,200
Hexafluoroethane	C_2F_6	10,000	8,630	12,200	18,200

10.2.1.2 Radiative Forcing 辐射强迫

- Radiative forcing (RF) is a measure of the influence that some climatic factor has in disturbing the balance between incoming solar radiation and outgoing infrared radiation of the Earth's atmosphere.
- The radiative forcing of different greenhouse gases is not the same, so a common metric, called carbon dioxide-equivalent (CO_2-eq) emissions and concentrations, is used. This is based on the radiative forcing of CO_2. A CO_2-eq for the emission of a long-lived greenhouse gas or mixture of gases is obtained by multiplying the emission of a greenhouse gas by its Global Warming Potential (GWP)

Chapter 10 Environmental sustainability

10.2 Unsustainable earth

10.2.1 Climate change

10.2.1.1 Greenhouse Effect

Example 10.1 Calculating carbon dioxide equivalent (CO_2-eq) over 100 years

(1) Calculate the CO_2-eq of 12 tonnes of methane emitted from a landfill for a 100-year period.

(2) If the landfill is next to a cement factory that emits 12 tonnes of CO_2 and 5 tonnes of N_2O, calculate the total CO_2-eq of these three gases for a 100-year period.

Chapter 10 Environmental sustainability

10.2 Unsustainable earth

10.2.1 Climate change

10.2.1.1 Greenhouse Effect

Example 10.1 Calculating carbon dioxide equivalent (CO_2-eq) over 100 years

(1) Calculate the CO_2-eq of 12 tonnes of methane emitted from a landfill for a 100-year period.

(2) If the landfill is next to a cement factory that emits 12 tonnes of CO_2 and 5 tonnes of N_2O, calculate the total CO_2-eq of these three gases for a 100-year period.

Solution

$$CO_2 - eq_{\text{methane}} = \text{Mass of methane} \times \text{GWP of methane}$$
$$CO_2 - eq_{\text{methane}} = 12 \text{ tonnes} \times 25$$
$$CO_2 - eq_{\text{methane}} = \boxed{300 \text{ tonnes}}$$

If the landfill is next to a cement factory that emits 12 tonnes of CO_2 and 5 tonnes of N_2O, calculate the total CO_2-eq of these three gases for a 100-year period.

$$CO_2 - eq_{\text{carbon dioxide}} = 12 \text{ tonnes}$$
$$CO_2 - eq_{\text{nitrous oxide}} = 5 \text{ tonnes} \times 298$$
$$CO_2 - eq_{\text{nitrous oxide}} = 1490 \text{ tonnes}$$

The total CO_2-eq of these three greenhouse gases (GHGs) is:

$$CO_2 - eq_{\text{methane}} + CO_2 - eq_{\text{carbon dioxide}} + CO_2 - eq_{\text{nitrous oxide}} = 300 + 12 + 1490 = \boxed{1802 \text{ tonnes}}$$

10.2 Unsustainable earth

10.2.1 Climate change

10.2.1.3 Intergovernmental Panel on Climate Change (IPCC) 政府间气候变化专门委员会

- The United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO)世界气象组织 established the IPCC in 1988.
- First Assessment Report was published by the IPCC in 1990. This led to the creation of the United Nations Framework Convention on Climate Change (UNFCCC)《联合国气候变化框架公约》
- The Second Assessment Report (1995) was used in preparing the Kyoto Protocol《京都议定书》
- https://www.un.org/zh/climatechange/cop28

10.2 Unsustainable earth

10.2.1 Climate change

10.2.1.4 Observed Changes in Climate

- The 2007 IPCC report documented the following climate trends.
- **Temperature** The Third Assessment Report showed a linear heating trend of 0.6℃for the period 1901 to 2000. The Fourth Assessment Report showed a linear trend of 0.74℃ for the period 1906 to 2005.
- **Sea Level** The global average sea level rose at an average rate of 1.8 mm/year from 1961 to 2003, and by 3.1 mm/year from 1993 to 2003.
- **Snow and Ice Extent** Arctic sea ice has decreased between 1973 and 2007 at a rate of about 10% ± 0.3% per decade. In September 2007, the sea ice extent was 23% below the previous record low.
- **Other Observations** Trends have been observed in the amount of precipitation, as well as an increase in intensity of tropical cyclone activity.

10.2 Unsustainable earth

10.2.1 Climate change

10.2.1.4 Observed Changes in Climate

- According to the China Blue Book on Climate Change (2023) released by the China Meteorological Administration (CMA), the global warming trend continues. the global average temperature in 2022 is 1.13°C above the pre-industrial level, the sixth highest value since meteorological observations were made in 1850; 2015 to 2022 are the eight warmest years since meteorological observations were made. The rate of warming in China is higher than the global level in the same period, and the average surface temperature in China in 2022 is 0.92°C above the normal value, one of the three warmest years since the beginning of the 20th century.
- The latest Greenhouse Gas Bulletin released by the World Meteorological Organization (WMO)states that global greenhouse gas concentrations soared again in 2023, hitting record highs and further exacerbating the warming trend.

10.2 Unsustainable earth

10.2.1 Climate change

10.2.1.5 Attribution of These Observed Climate Changes

There are a number of factors that might cause a global rise in temperature:

● **Solar Radiation** The contribution of direct solar irradiance forcing is small compared to the forcing attributed to greenhouse gases.

● **Earth's Position Relative to the Sun** Milankovitch cycles have great value for explaining ice ages and long-term changes in the climate, they are unlikely to have an impact on predictions of climate change in the immediate future, since orbital changes occur over thousands of years.

● **Change in Land Cover** Snow and ice tend to reflect incoming radiation, and vegetation (particularly forests) removes carbon dioxide from the atmosphere, thus reducing greenhouse gases.As the Earth's population increases, and deforestation occurs, less CO_2 is removed from the atmosphere, causing an increase in global CO_2.

● **Change in the Composition of the Atmosphere** There are ten primary greenhouse gases, four of which are naturally occurring, with the remaining six being due to industrial emissions. The four naturally occurring are water vapour, carbon dioxide, methane and nitrous oxide . The other six are perfluorocarbons), hydrofluorocarbons and sulfur hexafluoride.

10.2 Unsustainable earth

10.2.1 Climate change

10.2.1.5 Attribution of These Observed Climate Changes

There are a number of factors that might cause a global rise in temperature:

● The net effect of human activities since 1750 has been a warming trend (to which the IPCC attributes very high confidence), with an average radiative forcing of +1.6 W/m^2. In comparison, the radiative forcing due to natural solar irradiance for the same period is +0.12 W/m^2.

Chapter 10 Environmental sustainability

10.2 Unsustainable earth

10.2.2 Environmental depletion and degradation

- Environmental degradation is the deterioration of the environment through depletion of resources such as air, water and soil, the destruction of ecosystems and the extinction of wildlife.
- **Fresh Water Resources** Fresh water resources currently face the dual problems of quality and quantity.
- **Air Pollution** It is estimated that more than two million people die prematurely each year due to both indoor and outdoor air pollution.
- **Ozone Depletion** The ozone layer in the stratosphere protects life on Earth from harmful ultraviolet radiation.

10.2 Unsustainable earth

10.2.2 Environmental depletion and degradation

- **Land Use** Unsustainable land use has led to land degradation. This is caused by:
  - The use of chemicals and other pollutants rendering some areas too toxic to use.
  - Soil erosion due to overgrazing, or inappropriate agriculture that reduces the productivity of the land.
  - Depletion of soil nutrients as a result of land overuse.
  - Desertification caused by overuse of dry area land, and stresses on available water.

10.2 Unsustainable earth

10.2.2 Environmental depletion and degradation

- **Deforestation** The World Resources Institute regards deforestation as one of the world's most pressing land-use problems.
- **Biodiversity** Biodiversity decline is more rapid now than at any time in human history, and the associated loss of ecosystem services is a constant threat to future development.
- **Waste Disposal** The problem is particularly acute for hazardous wastes.

10.2 Unsustainable earth

10.2.3 Ecological footprint (EF)

- A core aspect of sustainability is the protection of natural capital, in particular the renewable resources constituting the ecosystem.
- Humanity has, until recently, been able to live within the capacity of the Earth to regenerate the resources used and to reabsorb the wastes generated.
- In 2007, the Food and Agriculture Organization of the United Nations (UN FAO) began warning about absolute food shortages, with resulting “biocapacity grabs”生物承载力抢夺, where one country buys cropland biocapacity in another. For example, South Korea has leased land in Tanzania to grow food, and other countries have similar arrangements with African countries (Reuters, 2010).

10.3 Addressing climate change

10.3.1 Greenhouse gases

- Despite international agreements, such as the Kyoto Protocol, to reduce the rate of greenhouse gas emissions, there has been no significant drop in the amount of these gases entering the atmosphere.
- A gas's contribution to the greenhouse effect is based on its molecular structure as well as its abundance.
- For example, methane has a GWP 25 times greater than carbon dioxide, but is present in lower concentrations, so its effect is smaller.

10.3 Addressing climate change

10.3.2 Reducing CO_2

- To reduce the amount of CO_2 being discharged into the atmosphere, the obvious route is to reduce the amount of energy we use, and to replace the burning of fossil fuels with other forms of energy. We consider some of the solar alternatives (solar heating, photovoltaic cells, wind, biofuels) as well as geothermal energy. We also need to consider energy efficiency to reduce CO2 emissions.
- The two primary sources of CO_2 emissions in the United States are power generation and transport. Renewable energy sources need to be found to replace the old ways of doing these things.Another reason for finding alternatives to fossil fuels, particularly oil, is energy security.
- Efficiency technologies, from better insulation to more efficient engines, are improving quickly.

10.3 Addressing climate change

10.3.3 Solar power

- Solar water heating, passive solar design for space heating and cooling, and solar photovoltaics for electricity are the most commonly used solar technologies for homes and businesses. Utilities and independent developers are also using solar photovoltaics and concentrated solar power to generate electricity on a larger scale.

10.3.3.1 Principles

- From the center outward, the Sun can be divided into a core, a radiative zone, a convective zone, a photosphere (the visible surface), and the solar atmosphere. The core is the only region of the Sun where thermal energy is generated through nuclear fusion reactions, which convert hydrogen into helium.The Sun’s surface temperature is about 5,800 K, which is often considered to be the effective blackbody temperature of the Sun. About 3.846 × 1026 W of thermal energy are generated within the core with heat transferred outward from the core through the other layers to the solar photosphere, and then into space in the form of sunlight (solar electromagnetic radiation) or kinetic energy of particles

10.3 Addressing climate change

10.3.3 Solar power

10.3.3.2 Applications

- **Solar Thermal Water heating:** sunlight can be used to heat water for domestic use with solar water heaters.
- **Solar cooling:** active solar cooling systems use solar thermal collectors to provide thermal energy to drive absorption chillers.Currently, most absorption chilling systems use a lithium-bromide or ammonia solution as the refrigerant. Neither of these would deplete ozone and are, therefore, preferable to compressor refrigerators that typically use ozone-depleting hydrochlorofluorocarbons (HCFCs)
- **Solar cooker:**
- **Electricity Generation :**Solar photovoltaics太阳能光伏板&Concentrated solar power (CSP)聚光型太阳能发电

10.3 Addressing climate change

10.3.3 Solar power

10.3.3.3 Pros and Cons 优点和缺点

- As one of the main sources of renewable energy, the advantage of solar energy is obvious: no matter whether using solar energy for heating, cooling or generating electricity, there is no emission of greenhouse gases and no fossil fuel consumption; it is renewable and there is a practically unlimited supply available. There are a great many technologies that use solar energy in various environments, and many of them are well developed and convenient to deploy.
- However, the Sun only shines during the day and does not shine consistently, depending on the weather. Energy storage and other complementary systems are usually required to provide a consistent power supply. Because solar energy is a diffuse source, the energy conversion efficiency is low and large collection areas are needed. For solar photovoltaic and CSP systems, the initial investment is high, so that the average cost for solar electricity is sometimes not competitive, compared to conventional thermal power system and other forms of renewable energy such as wind power.

Chapter 10 Environmental sustainability

10.3 Addressing climate change

10.3.4 Wind energy

10.3.4.1 Principles

- Solar radiation is, therefore, the ultimate power source driving the wind. It is estimated by meteorologists that about 1% of the total solar radiation energy received by the Earth is converted into wind (Musgrove, 1987). Wind power is the conversion of the kinetic energy 动能 of wind, into a useful form of energy, such as mechanical or electric power.
- The ideal or maximum fraction of total wind energy that can be captured by a windmill or a turbine is 59.3%. This is referred to as Betz's limit or Betz's law.
- Wind Power Density (WPD), with units of W/m^2, depends solely on wind speed and the air density, which decreases with increasing altitude and varies with temperature and humidity. Generally, wind speed is reduced near ground level (because of friction at the Earth's surface) and increases with altitude. As a simple rule of thumb, doubling the altitude typically increases wind speed by 10%.

Chapter 10 Environmental sustainability

10.3 Addressing climate change

10.3.4 Wind energy

10.3.4.2 Applications

- Modern wind turbines can be categorized into two basic types according to whether the rotation is about a horizontal or a vertical axis (EWEA, 2004).
  - Horizontal Axis Wind Turbines (HAWTs)
  - Vertical Axis Wind Turbines (VAWTs)

10.3 Addressing climate change

10.3.4 Wind energy

10.3.4.3 Pros and Cons

- Wind power is renewable and abundant.
- In addition to being clean, renewable and abundant, wind power is more cost effective for electricity generation than other forms of renewable energy.
- Even though offshore wind power is much more expensive than onshore higher speed wind power, it remains cheaper than solar photovoltaic (Solar PV) and concentrated solar power (Solar CSP) at present.
- Unfortunately, wind resources are quite area specific, and the best sites are often located in sparsely populated areas faraway from the population centers they need to serve.
- The wind is intermittent and unpredictable, so that the efficiencies of wind turbines are reduced.
- Furthermore, wind turbines may cause noise and visual problems and impact adversely on birds and wildlife.

10.3 Addressing climate change

10.3.5 Geothermal energy 地热能

10.3.5.1 Principles

- The literal meaning ("geo" means Earth and "thermal" means heat) for geothermal energy is the thermal energy stored and generated in the Earth. The heat in the Earth primarily has two sources: the residual heat left over from the Earth's formation (about 20%), and the decay of radioactive isotopes embedded in the Earth (80%), mainly comprising potassium (40K), thorium (232Th), and uranium (235U and 238U) (Turcotte & Schubert, 2002).
- In addition to the internal heat deep in the Earth, the top 10 m of the ground accumulates solar energy during summer and releases the heat during winter, which also contributes to geothermal energy.

10.3 Addressing climate change

10.3.5 Geothermal energy 地热能

10.3.5.1 Principles

- The literal meaning ("geo" means Earth and "thermal" means heat) for geothermal energy is the thermal energy stored and generated in the Earth. The heat in the Earth primarily has two sources: the residual heat left over from the Earth's formation (about 20%), and the decay of radioactive isotopes embedded in the Earth (80%), mainly comprising potassium (40K), thorium (232Th), and uranium (235U and 238U) (Turcotte & Schubert, 2002).
- In addition to the internal heat deep in the Earth, the top 10 m of the ground accumulates solar energy during summer and releases the heat during winter, which also contributes to geothermal energy.
- Natural hydrothermal systems can be roughly divided into three types: hot water, wet steam, and dry steam.

10.3 Addressing climate change

10.3.5 Geothermal energy 地热能

10.3.5.2 Applications

- The geothermal energy in hot springs has been used for bathing, space heating and even cooking for much of history. For modern applications,we will consider only two applications: electricity generation and direct heat.
- Electricity Generation There are four main types of geothermal power plants: dry steam, flash steam, binary cycle, and dry hot rock power plants (EERE, 2011)干蒸汽发电厂、闪蒸蒸汽发电厂、双循环发电厂和干热岩发电厂.
- Direct Applications (Direct heating&Geothermal heat pump)

Chapter 10 Environmental sustainability

10.3 Addressing climate change

10.3.5 Geothermal energy 地热能

10.3.5.3 Pros and Cons

- Geothermal energy is generally renewable and causes little impact on the environment. It is reliable and consistent compared to wind and solar energy. Geothermal energy is also cost-effective and does not require much land.
- However, large-scale use of geothermal energy, especially for electricity generation, has been limited to areas with known geothermal resources. New technologies, such as enhanced geothermal systems and geothermal heat pumps, have dramatically expanded the range and size of viable resources. However, there are still some problems that need to be considered, such as local depletion, which occurs when the extraction rate exceeds the regeneration rate in the heat reservoir.
- Furthermore, enhanced geothermal systems, and some traditional geothermal power plants, may affect land stability, due to underground work such as drilling wells, pumping underground water to the surface and injecting water into the deep ground, so that subsidence and even earthquakes may be triggered (Lund, 2007).

10.3 Addressing climate change

10.3.6 Carbon sequestration 碳封存

- “The term carbon sequestration is used to describe both natural and deliberate processes by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments (vegetation, soils, and sediments), and geologic formations” (USGS, 2008).
- In this section, we look only at deliberate efforts to capture and sequester carbon, which comprises four steps, although capture and compression usually go together:

  1 CO_2 capture

  2 Compression

  3 Transport

  4 Storage (geologic, ocean, and mineral carbonation)

10.4 Addressing resource depletion and environmental degradation

- The Ecological Footprint shows that current trends are not sustainable, and that without major changes to how we power the planet, and how we manage resources, we are headed for perhaps catastrophic climate change, a reduction in resources such as forests and fisheries, and ecosystems that will break down, with a corresponding loss of biodiversity.
- the Ecological Footprint and Life Cycle Assessment (LCA)

10.4 Addressing resource depletion and environmental degradation

10.4.1 Ecological footprint

- The Ecological Footprint is a simple and useful accounting tool to estimate human demand on the biosphere, and on the biosphere's regenerative capacity and ability to absorb waste. Representing the impact of human activity on the Earth's ecosystems, it is especially useful for revealing historical trends.
- If the Ecological Footprint is greater than the biocapacity of an area, then the population of that area is living unsustainably. In its most basic form, the Ecological Footprint (EF) can be expressed as:

$$EF = Demand/Yield \tag{10.7}$$

where:
Demand = the annual demand for a product
Yield = the annual yield of that product.

10.4 Addressing resource depletion and environmental degradation

10.4.1 Ecological footprint

- A global hectare corresponds to one hectare of biologically productive space with world-average productivity, and this makes Ecological Footprint areas comparable throughout the world. One Global Hectare (gha) is defined as one hectare with a productivity equal to the average productivity of the 12 billion bioproductive hectares on Earth. The Earth's total surface area is approximately 51 billion hectares. To obtain a standardized global hectare for the different land types, an equivalence factor for each land type is used.
- There are, in reality, two distinct Ecological Footprints at the national level – one for productivity (the amount a country produces, denoted EFP), and the second for consumption (the measure of production plus imports less exports, denoted EFC).

10.4 Addressing resource depletion and environmental degradation

10.4.1 Ecological footprint

The National Footprint Accounts track human demand for ecological services in terms of six land use types: cropland, grazing land, forest land, fishing grounds, built-up land, and carbon footprint.

$$EF_{PTotal} = EF_{PCrop} + EF_{PForest} + EF_{PGrazing} + EF_{PWater} + EF_{PBuilt} + EF_{PCarbon} \quad (10.8)$$

The EF_P for each land use type is given as:

$$EF_P = (P/Y_N) \times (\text{Yield Factor}) \times (\text{Equivalence Factor}) \quad (10.9)$$

where:

P = the amount of product produced

Y_N = the national average yield for P expressed in global hectares.

10.4 Addressing resource depletion and environmental degradation

10.4.1 Ecological footprint

The Ecological Footprint of consumption (EFC) is calculated as:

$$EF_C = EF_P + EF_I - EF_E \tag{10.10}$$

where EF_I and EF_E are the footprints for imported and exported commodity flows, respectively.

10.4 Addressing resource depletion and environmental degradation

10.4.1 Ecological footprint

- For each land use type (excluding cropland which is more complicated), the yield factor (YFL) is simply given by:

$$YF_L = (\text{National Yield})/(\text{World Yield}) \qquad (10.11)$$

- This is done because these land types are considered to have a single primary product, for example fish from fishing grounds.

Table 10.2 Yield factors for selected countries in 2007.

Yield factor	Cropland	Forest	Grazing land	Fishing grounds
World average	**1.0**	**1.0**	**1.0**	**1.0**
Germany	2.2	4.1	2.2	3.0
Japan	1.3	1.4	2.2	0.8
New Zealand	0.7	2.0	2.5	1.0
Zambia	0.2	0.2	1.5	0.0

10.4 Addressing resource depletion and environmental degradation

10.4.1 Ecological footprint

- The equivalence factor translates a specific land type (such as cropland or forest land) into the common unit of global hectares. This equivalence factor represents the world's average potential productivity of a given bioproductive area relative to the world average potential productivity of all bioproductive areas.

Table 10.3 Equivalence factors, 2007.

Area type	Equivalence factor
Cropland	2.51
Forest	1.26
Grazing land	0.46
Marine and inland water	0.37
Built-up land	2.51

10.4 Addressing resource depletion and environmental degradation

10.4.1 Ecological footprint

- Once the EFp is calculated for each land use type, we get the EFp for the country by summing the individual EFps. In other words, the primary production EF of a country is the sum of all the resources used, and all waste generated within that country's geographical borders. This includes all the areas within a country that are used to support the actual harvest of primary products (cropland, forest, grazing land , and fishing grounds), the country's infrastructure and hydropower (built-up land), and the area needed (forest) to absorb the country's CO_2 emissions (carbon footprint).
- The Ecological Footprint of consumption for a given country measures the biocapacity demanded by the final consumption of all the residents of the country. All manufactured products carry with them an embodied Footprint accounting for the resources and wastes that go into their production. The accounting method takes into consideration all aspects of production and demand

$$EF_C = EF_P + EF_I - EF_E \qquad (10.13)$$

where EF_I and EF_E are the footprints embodied in imported and exported commodity flows respectively.

10.4 Addressing resource depletion and environmental degradation

10.4.1 Ecological footprint

- Calculating Biocapacity As already mentioned, biocapacity is the complement to the Footprint. The Biocapacity (BC) of a nation is the sum of all its bioproductive areas. Each unit of bioproductive area is transformed into global hectares (gha) by the following equation:

$$BC = A \times EQF \times YF \qquad (10.17)$$

where:
A is the area available for a given land use type
EQF and YF are the equivalence and yield factors, respectively.

- If the Ecological Footprint is greater than the Biocapacity, this is evidence of overshoot, where use exceeds natural supply.

Chapter 10 Environmental sustainability

10.4 Addressing resource depletion and environmental degradation

10.4.1 Ecological footprint

Example 10.6 Calculating total biocapacity and EFC Given the following data, calculate the Total Biocapacity for Germany, and the per person EFC for Japan.

	Zambia (1)	Japan (2)	Germany (3)
Biocapacity			
Cropland	2.1	15.02	75.73
Grazing land	13.57	0.43	7.39
Forest land	11.59	43.48	53.43
Fishing grounds	0.34	9.39	6.2
Built-up land	0.21	8.01	15.73
Total biocapacity (million gha)	27.81	76.32	
EF_c			
Cropland	1.93	72.1	102.89
Grazing land	2.23	8.47	16.91
Forest land	4.29	34.99	50.08
Fishing grounds	1.03	79.54	10.8
Built-up land	0.21	8.01	222.08
Carbon footprint	1.54	399.33	15.73
Total EF_C (million gha)	11.24		418.46
Population (millions)	12.31	127.4	82.34
EF_P (per person)	0.78	3.55	4.72
EF_I	0.18	2.05	3.97
EF_E	0.05	0.87	3.6

10.4 Addressing resource depletion and environmental degradation

10.4.1 Ecological footprint

Example 10.6 Calculating total biocapacity and EFC Given the following data, calculate the Total Biocapacity for Germany, and the per person EFC for Japan.

Solution

Sum up the biocapacities of each land use type for Germany in Column (3):

$$BC_{Germany} = 75.73 + 7.39 + 53.43 + 6.2 + 15.73$$

$$BC_{Germany} = \boxed{158.48 \text{ million gha}}$$

10.4 Addressing resource depletion and environmental degradation

10.4.1 Ecological footprint

Example 10.6 Calculating total biocapacity and EFC Given the following data, calculate the Total Biocapacity for Germany, and the per person EFC for Japan.

Solution

To calculate the per person EFC for Japan, we can either sum the EFCs for each land use type in Column (2), and divide by the population to get the per person value:

$$EF_{C\ Japan} = 72.1 + 8.47 + 34.99 + 79.54 + 8.01 + 399.33$$

$$EF_{C\ Japan} = 602.44 \text{ million gha}$$

$$EF_{C\ Japan}(\text{per person}) = \frac{602.44 \times 10^6}{127.4 \times 10^6} = \boxed{4.73}$$

$$EF_C = EF_P + EF_I - EF_E$$

$$EF_C = 3.55 + 2.05 - 0.87 = \boxed{4.73}$$

Or, alternatively, we can use equation (10.13), since we are already given the data per person:

10.4 Addressing resource depletion and environmental degradation

10.4.1 Ecological footprint

Example 10.6 Calculating total biocapacity and EFC Given the following data, calculate the Total Biocapacity for Germany, and the per person EFC for Japan.

Solution

To see whether Japan's EF exceeds its biocapacity, we determine the total per person biocapacity:

$$BC_{Japan}(\text{per person}) = \frac{76.32}{127.4} = \boxed{0.60}$$

Japan's overshoot is therefore:

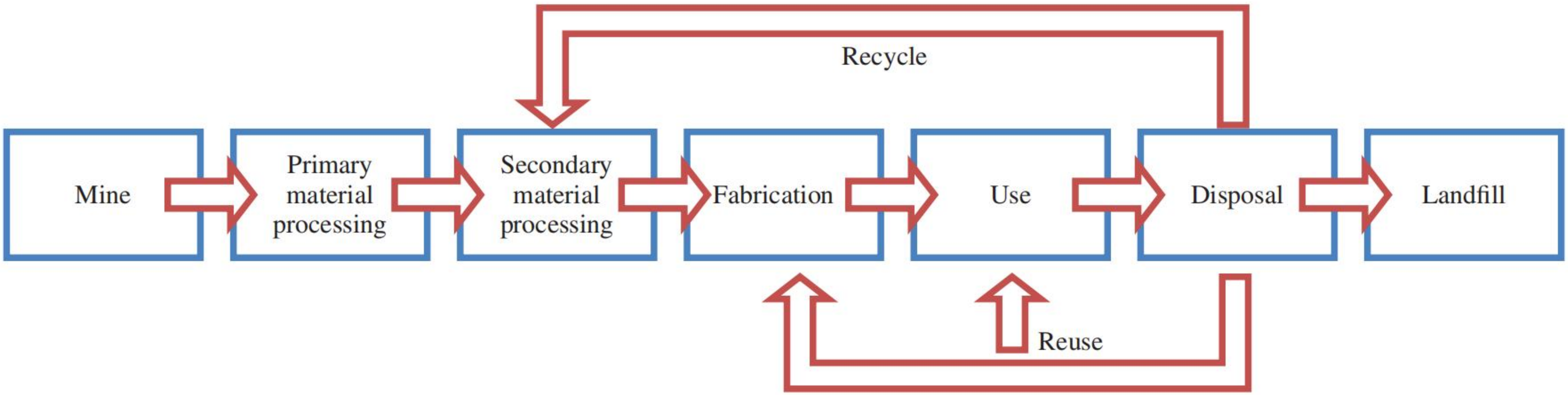
$$4.73 - 0.60 = \boxed{4.13 \text{ gha per person}}$$

10.4 Addressing resource depletion and environmental degradation

10.4.2 Life cycle assessment (LCA)

10.4.2.1 What is Life Cycle Assessment?

- LCA requires careful energy and materials balances for all the stages of the life cycle,



10.4 Addressing resource depletion and environmental degradation

10.4.2 Life cycle assessment (LCA)

10.4.2.1 What is Life Cycle Assessment?

- It is necessary to evaluate the entire life cycle of goods and services to make informed decisions, and the results are not always apparent. For example, it has been shown that paper bags are not obviously superior to plastic bags in terms of using less energy and materials and producing less waste. Paper requires cutting trees and transporting them to a paper mill, both of which use substantial energy. Paper-making results in emissions to air and discharges to water of chlorine and biological waste. After use, the paper bag goes to a landfill, where it gradually decays, releasing methane. Plastic, in contrast, is made from petroleum, with relatively low environmental discharges. In short, it is not obvious which product is better without resorting to LCA.

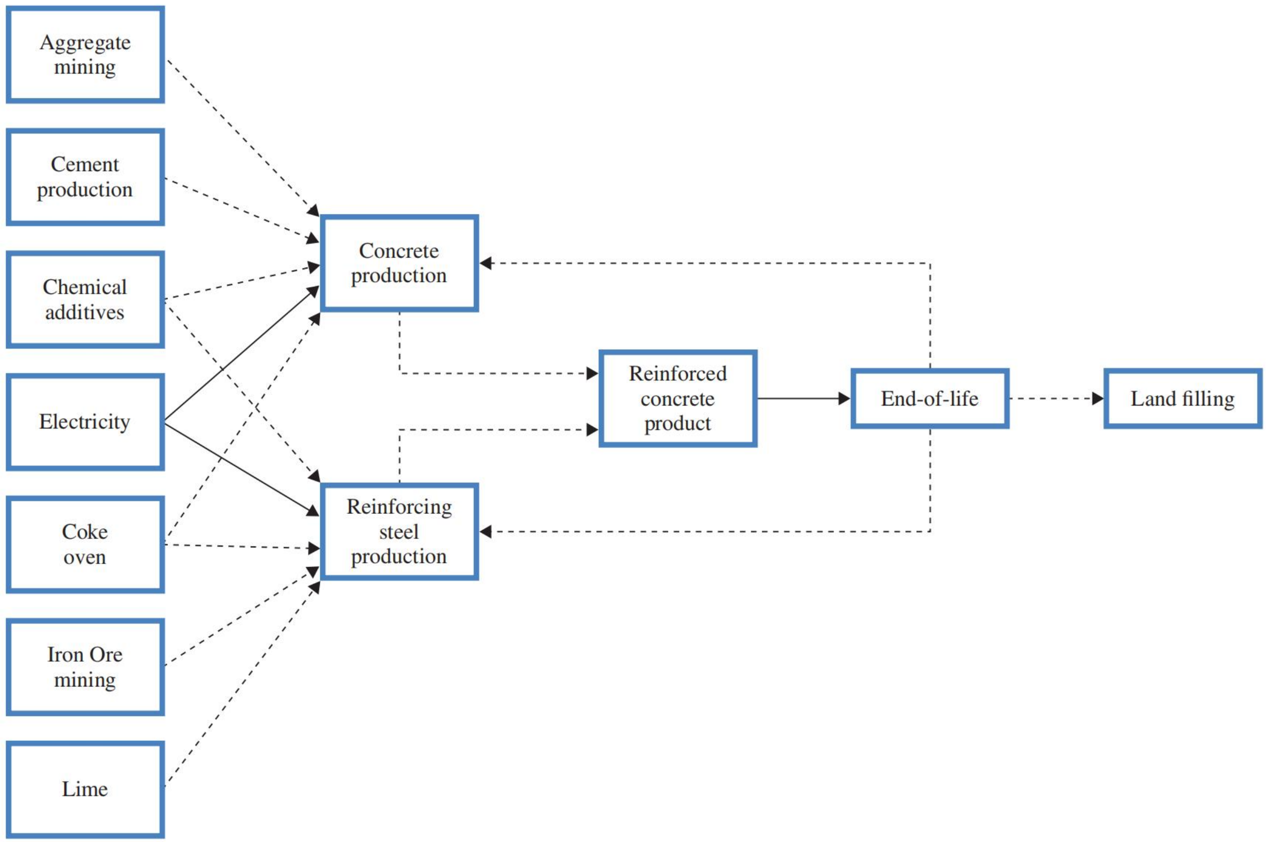
Chapter 10 Environmental sustainability

10.4 Addressing resource depletion and environmental degradation

10.4.2 Life cycle assessment (LCA)

10.4.2.3 The Input-Output Approach to Life Cycle Assessment

In the United States, the Society of Environmental Toxicology and Chemistry (SETAC) and the US Environmental Protection Agency (EPA) have played leading roles in standard LCA. The SETAC-EPA approach can be illustrated with the life cycle of reinforced concrete Pavement.Each of the boxes and transportation links requires a separate process model, with resource requirements and environmental impacts.



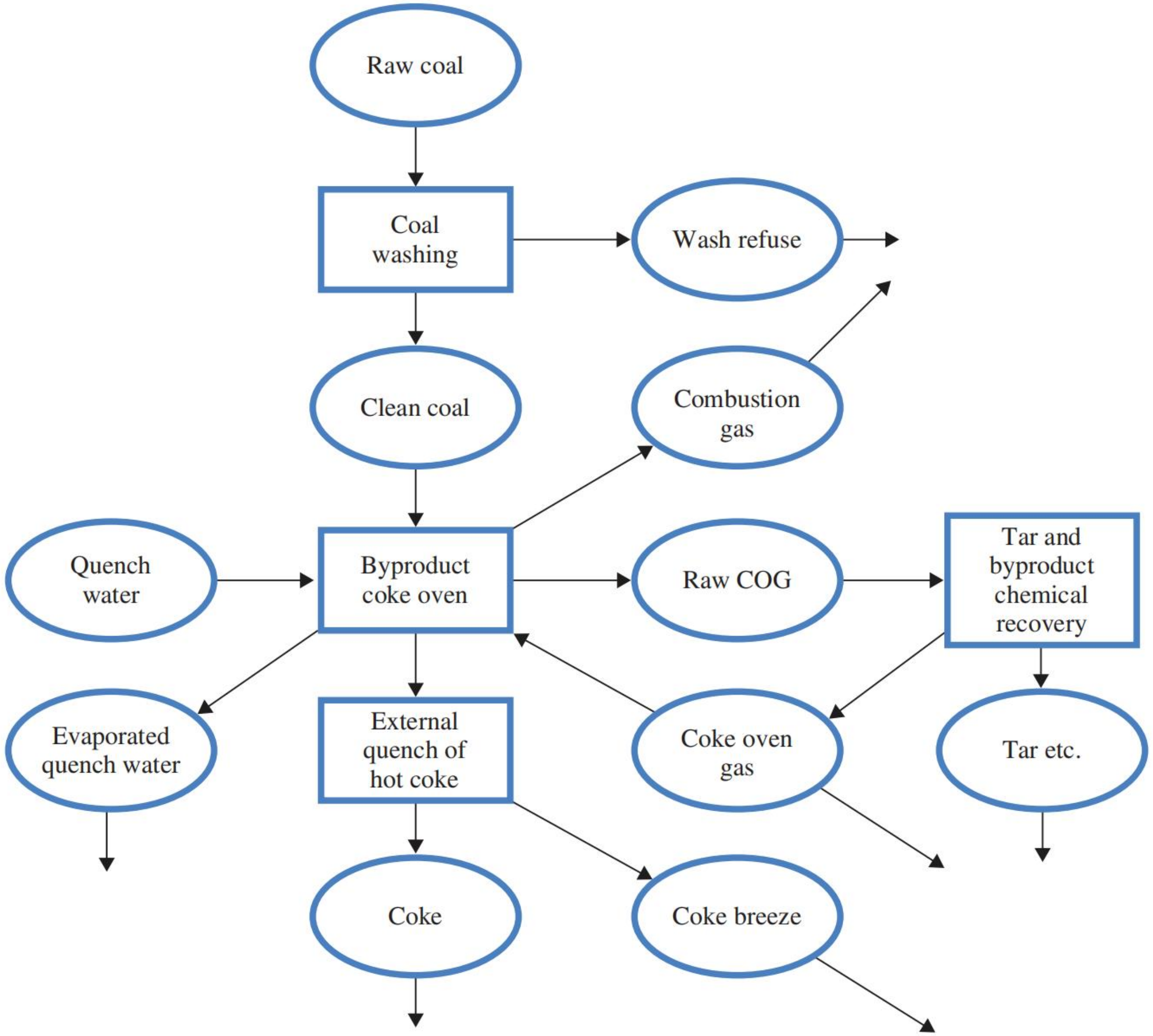
Chapter 10 Environmental sustainability

10.4 Addressing resource depletion and environmental degradation

10.4.2 Life cycle assessment (LCA)

10.4.2.2 The SETAC-EPA Approach to Life Cycle Assessment

- A second approach, the economic input-output life cycle assessment (EIO-LCA) approach, takes an aggregate view of the sectors producing all of the goods and services in the economy, compared with the far more detailed SETAC-EPA process approach.
- The input-output flows among all these sectors are assumed to be linearly related.



10.4 Addressing resource depletion and environmental degradation

10.4.2 Life cycle assessment (LCA)

Table 10.4 Comparison of the SETAC-EPA and EIO approaches to life cycle assessment.

	SETAC-EPA approach	EIO approach
Pros	Detailed process specific analyses. Specific product comparisons. Process improvements, weak point analyses. Future product development assessments.	Economy-wide, comprehensive assessments. System-based LCA: industries, products, services, national economy. Sensitivity analyses, scenario planning. Publicly available data, reproducible results. Future product development assessments. Information on every commodity in the economy.
Cons	System boundary setting is subjective. Tends to be time-intensive and costly. New process design difficult. Use of proprietary data. Cannot be replicated if confidential data are used Uncertainty in data.	Some product assessments contain aggregate data. Process assessments are difficult. Difficulty in linking dollar values to physical units. Economic and environmental data tend to reflect past practices. Imports treated as US products. Difficult to apply to an open economy (with substantial non-comparable imports). Non-US data availability a problem Uncertainty in data.

10.4 Addressing resource depletion and environmental degradation

10.4.3 Measures of sustainability

In order to achieve sustainable development, human wealth, and well-being, multi-dimensional indicators are essential. The success of GDP as a measure has been its simplicity but, as a measure of sustainability or even well-being, it is obviously inadequate.

Chapter 10 Environmental sustainability

HOMEWORK

Calculating total biocapacity and EFC
Given the following data, calculate the Total Biocapacity and the per person EFC for Germany， Japan and Zambia.

	Zambia (1)	Japan (2)	Germany (3)
Biocapacity			
Cropland	2.1	15.02	75.73
Grazing land	13.57	0.43	7.39
Forest land	11.59	43.48	53.43
Fishing grounds	0.34	9.39	6.2
Built-up land	0.21	8.01	15.73
Total biocapacity (million gha)	27.81	76.32	
EF_c			
Cropland	1.93	72.1	102.89
Grazing land	2.23	8.47	16.91
Forest land	4.29	34.99	50.08
Fishing grounds	1.03	79.54	10.8
Built-up land	0.21	8.01	222.08
Carbon footprint	1.54	399.33	15.73
Total EF_C (million gha)	11.24		418.46
Population (millions)	12.31	127.4	82.34
EF_P (per person)	0.78	3.55	4.72
EF_I	0.18	2.05	3.97
EF_E	0.05	0.87	3.6

Thanks!