

# DP IB Environmental Systems & Societies (ESS): SL

## 7.2 Energy Sources Uses & Management

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## Energy Sources & Sustainability

### Renewable & Non-renewable Energy Sources

- Energy sources are classified into renewable and non-renewable categories
  - This is based on their ability to **regenerate** within a human lifespan

### What are renewable energy sources?

- Renewable energy comes from energy sources that will **not run out** and includes:
  - Wind energy
  - Solar energy
  - Tidal energy
  - Biomass (wood)
  - Geothermal energy
  - Hydropower
- Once in place, these renewable energy sources do not produce any greenhouse gas emissions (except for **biomass**)
  - It is important to note that greenhouse gases may be emitted in the production, construction and transport of the equipment required for renewable energy sources
- Advantages of all:
  - **Reduces dependence on fossil fuels** and foreign energy sources
    - This promotes energy independence and security
  - The renewables industry **creates jobs** in manufacturing, installation, operation and maintenance of renewable infrastructure

### Wind energy

- Wind energy harnesses the kinetic energy of moving air to generate electricity
  - It involves the use of wind turbines
  - These have large blades that spin when the wind blows
  - The rotating blades transfer kinetic energy to a generator, which converts it into electrical energy

- **Advantages:**

- Abundant energy source
- No greenhouse gas emissions or air pollutants produced during operation
- Land beneath turbines can often still be used for farming or other purposes
- Can be installed offshore (in the sea) to minimise land use conflicts
- Installation and running costs have decreased significantly, making it competitive with non-renewable energy sources
- Can be small- or large-scale

- **Disadvantages:**

- Intermittent (non-constant) energy source dependent on wind availability
- Visual and noise pollution can affect local communities
- Initial high capital investment for turbines and infrastructure
- Potential impact on wildlife, particularly birds and bats flying into the turbine blades
- Wind farms require large areas of land, which can have an impact on agricultural or natural landscapes

## Solar energy

- Solar energy uses photovoltaic (PV) panels that transfer energy from sunlight to produce an electrical current, generating electrical power

- **Advantages:**

- Abundant energy source
- No greenhouse gas emissions or air pollutants produced during operation
- Suitable for various scales of application (from house rooftops to very large solar farms)
- Can be integrated into existing buildings and infrastructure
- Solar is progressively becoming less expensive and more efficient
- Solar energy can be generated in remote places where they don't have electricity (e.g. to power solar street signs in rural areas)

- **Disadvantages:**

- Intermittent (non-constant) energy source dependent on sunlight availability
- Initial high capital investment for solar panels and equipment
- Requires significant land area for solar farm installations (which could otherwise be used for agriculture)
- Energy storage solutions needed for night-time or cloudy days
- Potential environmental impact during manufacturing and disposal of panels (electronic waste)
- Some people dislike the appearance of large solar farms (visual pollution)

## Tidal energy

- Tidal energy uses the energy of rising and falling tides to turn a turbine and generate electricity

- **Advantages:**

- Abundant energy source
- No greenhouse gas emissions or air pollutants produced during operation
- Predictable and reliable source of energy due to regular tidal patterns
- Can produce a large amount of electricity at short notice
- Minimal visual impact when installed underwater
- Long lifespan of tidal turbines with minimal maintenance

- **Disadvantages:**

- High initial costs
- Limited availability of suitable sites
- Potential environmental impact on marine ecosystems and fish migration
- Maintenance challenges and costs due to underwater installations
- Possible interference with shipping lanes and navigation

## Biomass (wood)

- Biomass energy uses organic materials such as wood to generate heat or electricity
- **Advantages:**
  - Renewable resources and carbon neutral if managed sustainably
  - Readily available in many regions, especially rural areas
- **Disadvantages:**
  - Carbon dioxide and air pollution from combustion emissions
  - Deforestation risk and habitat loss if not sustainably managed
  - Impact on indoor air quality if not properly ventilated

## Geothermal energy

- Geothermal energy harnesses heat from within the Earth's crust for electricity generation or heating purposes.
  - The Earth's interior is extremely hot
  - Water can be poured into shafts below the Earth's surface
  - The water is heated and returned via another shaft as steam or hot water
  - Steam can be used to turn a turbine and generate electricity
  - The hot water can also be used to heat homes
- **Advantages:**
  - Sustainable energy source
  - Reliable and stable source of energy available at all times
  - Small land footprint compared to other renewable sources (e.g. wind and solar)
  - Geothermal power stations are usually small compared to nuclear or fossil fuel power stations
  - Long lifespan of geothermal plants with low operating costs
- **Disadvantages:**
  - Site-specific; limited to regions with near-surface geothermal activity
  - High initial drilling and exploration costs
  - Can result in the release of greenhouse gases from underground
  - Geological risks such as earthquakes or ground subsidence

## Hydropower

- Hydropower uses flowing water to generate electricity through turbines in dams
- **Advantages:**
  - Reliable and predictable source of energy
  - Low greenhouse gas emissions during operation
  - Multi-purpose benefits, including flood control and irrigation
  - Long lifespan of hydroelectric plants with low operating costs
  - Can respond to demand quickly, generating large scale amounts of electricity in a short period of time
- **Disadvantages:**
  - Disruption of river ecosystems and fish migration routes
  - High initial capital costs for dam construction and infrastructure
  - Dam construction and reservoir formation floods habitats and can require relocation of human communities
  - Climate change impacts on water availability is affecting reservoir levels, making them less reliable

## What are non-renewable energy sources?

- Non-renewable energy comes from energy sources that will eventually run out, including:
  - Fossil fuels
  - Nuclear energy (using uranium as a fuel)

### Fossil fuels

- Fossil fuels include:
  - **Coal**
  - **Crude oil**, which is refined into petrol, diesel and other fuels
  - **Natural gas** (mostly methane), which is used in domestic boilers and cookers
- Fossil fuels are formed from the remains of **plants** and **animals**
  - **Chemical energy** stored in fossil fuels originally came from **sunlight**
  - Energy from the sun was transferred to chemical energy stores within plants through photosynthesis (plants use energy from sunlight to make food)
  - Animals ate the plants and the energy was then transferred to their chemical store

- **Advantages**

- The current systems of transport and electricity generation used by human societies rely heavily on fossil fuels
  - These fossil fuels are generally readily available on a daily basis
- In the past, fossil fuels have been reliable for large-scale energy production (although this is changing as supplies start to become depleted and prices rise)
- Efficient—fossil fuels typically have a high energy density (they produce a large amount of energy per kilogram)

- **Disadvantages**

- It takes millions of years for fossil fuels to form:
  - This is why they are considered a non-renewable energy resource
- The increasing demand for decreasing supply causes prices to increase
  - Fossil fuels are predicted to completely run out within the next 200 years
- Burning fossil fuels pollutes the atmosphere with harmful gases such as:
  - Carbon dioxide, which contributes to the greenhouse effect
  - Sulphur dioxide, which produces acid rain
  - Both carbon and sulphur can be captured upon burning, preventing them from being released into the atmosphere, but this is expensive to do
- Oil spills can occur during transport of fossil fuels, which damage the marine environment and wildlife over very large areas
- Prices fluctuate rapidly
- Conflict and political disagreements (such as the war in Ukraine) can have an impact on supplies



## Nuclear Energy

- Energy stored in the nucleus of atoms can be released when the nucleus is broken in two:
  - This is known as **nuclear fission**
- Nuclear power stations use fission reactions to create **steam** to turn **turbines** to generate electricity
- Nuclear power is a low-carbon, low-emission, non-renewable resource
  - However, it is controversial due to the radioactive waste it produces and the potential scale of any accident
- **Advantages**
  - No pollution released into atmosphere
  - Nuclear reactors are perfectly safe as long as they are functioning properly (rigorous safety checks must be routinely carried out and rigorous safety procedures followed)
  - Nuclear power stations can generate electricity reliably on a large scale to be available as needed
  - Small amounts of uranium are needed, and large reserves are available
  - Reduces reliance on fossil fuels
  - Increases energy security
- **Disadvantages**
  - There is a finite supply of uranium ore, so nuclear power is a non-renewable resource
  - Nuclear fuels produce radioactive waste, which needs to be stored for thousands of years
  - Safe ways of storing radioactive waste are very expensive
  - If an accident occurs at a nuclear reactor, radioactive waste can leak out and spread over large areas
  - The cost of decommissioning (shutting down) nuclear power plants is very high

## Sustainability of Energy Sources

- Energy sustainability refers to meeting current energy demands without compromising the ability of future generations to meet their needs
- The sustainability of energy sources can vary greatly depending on:
  - Whether they are renewable or non-renewable
  - Their environmental impact

## Environmental cost of non-renewable energy

### Fossil fuels

- **Extraction:** mining for coal and drilling for oil and gas can destroy habitats and lead to soil erosion and water contamination
- **Refining crude oil:** this process releases harmful chemicals and contributes to air and water pollution
- **Liquefaction of natural gas:** turning gas into liquid for easier transportation emits carbon dioxide and other greenhouse gases

### Nuclear energy

- **Mining of uranium:** extracting uranium for nuclear power plants is energy-intensive and leaves behind radioactive waste
- **Nuclear waste:** long-term storage of nuclear waste is difficult, as it remains hazardous for thousands of years

## Environmental cost of renewable energy Sources

- Renewable energy comes from sources that can be naturally replenished, such as the sun, wind and water
- These sources tend to have a **lower** environmental impact
- However, they can still have significant (sometimes '**hidden**') environmental costs, including:
  - **Manufacturing:** producing **renewable energy devices** requires energy and raw materials, leading to environmental damage
  - **End-of-life management:** recycling components from solar panels, wind turbines and batteries is often expensive and not always efficient, leading to waste and pollution

## Examples of renewable energy devices

- **Wind turbines**

- Challenges:
  - Wind turbines require rare earth elements for magnets and motors, such as neodymium
  - At the end of their life, turbine blades are difficult to recycle and often end up in landfills

- **Solar panels**

- Challenges:
  - The production of solar panels requires mining for materials like silicon and rare earth elements
  - Solar panels have a limited lifespan (20–30 years) and need careful disposal to avoid chemical pollution

- **Tidal barrages**

- Tidal barrages use the movement of tides to generate energy
- Challenges:
  - Building tidal barrages can disrupt local ecosystems, affecting fish and marine life
  - Barrages are large and expensive to construct and maintain

## Rare earth elements in renewable energy

- Renewable technologies, like electric vehicles (EVs) and wind turbines, rely on rare earth elements for efficient energy conversion
- However, these elements are difficult to mine and refine, leading to **sustainability issues**, including:
  - **Energy-intensive extraction:**
    - Extracting rare earth elements requires significant energy (e.g. for mining machinery), contributing to greenhouse gas emissions
  - **Mining impacts:**
    - Mining for rare earth elements can cause severe environmental damage, including:
      - **Water contamination:** mining processes release toxic chemicals into nearby water sources, affecting both surface water and groundwater
      - **Habitat destruction:** clearing land for mining operations and access routes can destroy local ecosystems, disrupt wildlife habitats and cause deforestation

- **Dust pollution:** dust from cutting, drilling and blasting rocks accumulates in surrounding areas, leading to air pollution and increasing the risk of respiratory diseases for nearby communities



## Energy Consumption & Choices

### Energy Consumption

- Energy consumption refers to the total amount of energy used by individuals, industries and countries
- As populations grow and individual demand increases, global energy consumption continues to rise
- **Meeting energy needs** whilst also managing **environmental** and **economic impacts** is a significant challenge

### Global trends in energy consumption

#### Rising demand

- **Population growth:**
  - As the global population increases, so does energy demand
  - More people need energy for electricity, transport, heating and cooling
- **Per capita energy demand:**
  - People are using more energy per person
    - Particularly in developing countries where industrialisation and living standards are improving

## Energy production and consumption changes

- Fossil fuels like coal, oil, and natural gas continue to supply the majority of the world's energy
- **Renewable energy** (e.g. wind, solar and hydro) is growing but still provides a smaller portion of global energy
  - E.g. in 2022, 80% of the world's energy came from fossil fuels, with renewable energy making up 12.7%

## Reasons for changes in energy use

- **Economic development:**
  - As countries become wealthier, they tend to use more energy for:
    - Industrial processes
    - Transportation
    - Technology
  - For example, India's energy consumption is rapidly increasing as it develops its manufacturing sector and infrastructure
- **Environmental concerns:**
  - Global concerns about climate change are driving a shift towards cleaner energy sources like solar and wind
  - Governments are setting targets to:
    - Reduce carbon emissions
    - Invest in renewable energy
  - For example, the European Union aims to achieve carbon neutrality by 2050, which requires a massive reduction in fossil fuel use

## The role of fossil fuels

- Despite environmental concerns, fossil fuels still play a crucial role in supporting industries that are hard to power with renewable energy:
- **Steel and concrete industries:**
  - The production of steel and concrete relies heavily on **coal** and **natural gas**
  - Renewable energy is not yet suitable for these high-energy processes

- For example, China is the world's largest producer of steel, and its steel industry is responsible for a significant portion of global coal consumption
- **Synthetic fertilisers:**
  - **Natural gas** is essential for producing **ammonia**
    - Ammonia is a key ingredient in synthetic fertilisers that support global agriculture
    - As global food demand increases, the need for synthetic fertilisers (and therefore natural gas) is likely to continue

## Meeting the growing demand for energy

### Changing energy production resources

- **Increased renewable energy:**
  - Investing in renewable energy sources can help meet rising demand while reducing reliance on fossil fuels
- **Energy storage:**
  - Storing energy efficiently is key to managing renewable sources that are not able to provide a constant supply, like solar and wind
    - For example, Tesla's battery storage systems in Australia help store surplus solar energy for use at night or during low-wind periods

### Reducing energy consumption

- **Energy efficiency:**
  - Improving the energy efficiency of appliances, vehicles and buildings can significantly reduce overall consumption
    - For example, the UK government has introduced stricter building regulations
    - These require homes to be more energy efficient, helping to lower overall energy demand
- **Behavioural changes:**
  - Encouraging individuals and industries to use less energy can make a big difference

## Energy Choices

- Energy choices refer to the decisions a country makes about how it generates and consumes energy
- There are many factors that affect decisions, such as:
  - Economic cost
  - Pollution
  - Energy efficiency
  - Availability
  - Energy security

## Factors influencing energy choices

### Economic cost

- The cost of building and maintaining energy infrastructure plays a big role in energy choices
  - **Fossil fuels:** often cheaper to develop initially but come with high environmental and long-term costs
  - **Renewables:** may have higher upfront costs but offer long-term savings and environmental benefits
    - For example, solar energy is becoming more cost-competitive in many countries due to advances in technology and falling costs

### Pollution

- Some energy sources cause more pollution than others
- Many countries are trying to balance energy needs with environmental health
  - **Fossil fuels:** emit large amounts of greenhouse gases and contribute to air pollution
  - **Renewables:** produce little to no pollution during operation

### Energy efficiency

- Energy efficiency refers to how well energy is used and conserved.



- **Fossil fuels:** often less efficient and result in energy waste during burning
- **Renewables:** can be efficient but some rely on weather conditions

## Availability

- The natural resources available to a country influence its energy choices
  - **Fossil fuels:** countries with large reserves of coal, oil, or natural gas are likely to use them as major energy sources
  - **Renewables:** depend on geographic features like sunlight, wind, or water availability

## Energy security

- Energy security refers to a country's ability to meet its energy needs reliably and without being overly dependent on foreign sources
  - **Fossil fuels:** many countries that rely on imported oil or gas face risks from fluctuating prices or geopolitical issues
  - **Renewables:** provide more energy security, as they are often produced locally and are not subject to international market fluctuations

## Energy Storage & Conservation

### Energy Storage

- Energy storage is important for managing the supply of energy, especially from **renewable sources**
- This is because many renewable sources do not produce a **consistent flow of energy**
- By storing energy, countries can ensure a **reliable supply** even when renewable sources like wind or solar power are not generating electricity

### The need for energy storage

- Some renewable energy sources, such as wind and solar, produce energy **intermittently**
- This means they only generate power when conditions are right:
  - Wind power: only produces electricity when the wind is blowing
  - Solar power: only generates electricity during the day when there is sunlight
- Because of this, there can be times when **energy supply does not meet demand**
- Energy storage systems help solve this problem by:
  - Storing excess energy when production is high
  - Releasing it when **demand exceeds supply**

### Energy storage solutions

There are several ways to store energy to ensure supply can meet demand, including the following:

#### Batteries

- Store electricity as chemical energy, which can be released when needed
  - **Uses:** common in electric vehicles and home solar systems
  - **Example:** Tesla Powerwall batteries store energy from solar panels and can supply power to homes during outages or high demand periods

#### Pumped hydroelectricity storage (PHS)

- PHS stores energy by pumping water to a higher reservoir when there is surplus electricity
- When electricity demand is high, the water is released back down to a lower reservoir, turning turbines to generate electricity

- **Uses:** large-scale energy storage used by national grids
- **Example:** Dinorwig Power Station in Wales is one of the largest PHS systems and is used to balance electricity supply in the UK
- Advantages of PHS:
  - **Large capacity:** can store huge amounts of energy from excess electricity generated during periods of high renewable energy production (e.g. when the wind is blowing strongly or during peak solar energy generation)
  - **Reliable:** provides quick response to sudden demand increases (known as peak-shaving)
  - **Long lifespan:** PHS plants can operate for decades with low maintenance, contributing to their sustainability
- Disadvantages of PHS:
  - **Geographic limitations:** requires specific landforms (mountains, valleys) and large reservoirs, limiting where it can be built
  - **Environmental impact:** constructing dams and reservoirs can damage ecosystems and disrupt local wildlife
  - **Economic costs:** can have very high initial costs to build

## Fuel cells

- Fuel cells convert stored chemical energy (often hydrogen) directly into electricity
  - **Uses:** used in transportation (e.g. hydrogen-powered vehicles) and backup power systems
  - **Example:** Japan is investing in hydrogen fuel cells for its energy transition, particularly for powering vehicles and buildings

## Thermal storage

- Stores heat energy, which can be used to generate electricity later or provide heating
  - **Uses:** often used with solar power plants, where excess solar energy is stored as heat and converted to electricity during low sunlight
  - **Example:** the Crescent Dunes Solar Energy Project in the US uses molten salt to store solar energy as heat, which is then used to generate electricity after sunset

## Managing energy demand: peak–shaving

- Energy storage systems can be used for **peak–shaving**
  - This is the process of levelling out periods of high demand to ensure supply meets demand
- When there is a peak in electricity usage (like during cold winter evenings), stored energy can be released to meet the extra demand
  - This avoids blackouts or the need to turn on extra power plants

## Energy Conservation & Efficiency

### What is energy conservation?

- Energy conservation means **changing our behaviour** to use less energy
- It includes small daily actions such as:
  - Turning off lights when not in use
  - Reducing the use of heating or air conditioning by wearing appropriate clothing or using natural ventilation
  - Travelling less by fuel-driven vehicles and opting for walking, cycling or public transport instead

### What is energy efficiency?

- Energy efficiency means using **technologies and designs** that require less energy to perform the same task
- This can include:
  - Installing **low–energy LED lighting** in homes and buildings
  - Using **energy–efficient appliances** (e.g. the latest washing machines and fridges with high energy–efficiency ratings)
- Developing **fuel–efficient transportation** methods, such as electric vehicles (EVs)
- Designing **buildings to conserve heat** through better insulation, reducing the need for heating and cooling
  - For example, the use of double-glazed windows in homes increases energy efficiency by keeping heat inside, reducing the need for heating systems

## The importance of energy conservation and efficiency

- Energy conservation and efficiency help reduce energy demand and waste
- These strategies make countries less dependent on **importing energy resources**
  - This reduces costs and improve energy security
- They also contribute to **reducing carbon emissions**
  - This helps combat climate change

## Examples of energy conservation and efficiency

### Smart lighting systems

- Energy-efficient lighting like **LED bulbs** and **motion sensors** are designed to reduce electricity use
- Motion sensors ensure that lights are only on when needed, reducing waste in public spaces and large buildings
- **Effectiveness:**
  - LEDs use up to 80% less energy than traditional bulbs, making them a cost-effective solution for reducing electricity use

### Passive solar building design

- Passive solar design uses **natural sunlight** to heat buildings, reducing the need for artificial heating
- Buildings are designed with large windows facing the sun and materials that store and release heat efficiently
- **Effectiveness:**
  - Passive solar design is effective in regions with consistent sunlight, helping reduce energy bills and making homes more energy-efficient

### Designing goods to be easily recycled

- The **circular economy** aims to reduce waste by designing products that can be easily reused, repaired or recycled
- By creating products with **longer lifespans** and using **recyclable materials**, less energy is needed for producing new items
- **Effectiveness:**
  - Designing goods to be recycled reduces the energy needed for producing new materials, cutting down energy demand in industries

## Commercial shipping with sails

- One innovative way to improve energy efficiency in the shipping industry is by designing ships with sails (wind-assisted propulsion)
- Modern ships can use **large, automated sails**, known as **rotor sails** or **kite sails**, to harness wind energy and reduce fuel consumption
  - This reduces greenhouse gas emissions
- **Effectiveness:**
  - Ships using wind-assisted propulsion can reduce fuel consumption by 10–30%, depending on wind conditions



*Cargo ship with four large rotor sails (photo by Alan Jamieson, from Wikimedia Commons)*