HL IB Environmental Systems & Societies (ESS)

Your notes

7.2 Energy Sources Uses & Management

Contents

Energy Sources & Sustainability

Your notes

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


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Wind farms can be harmful to wildlife, which may mean they shouldn't be built in certain areas

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

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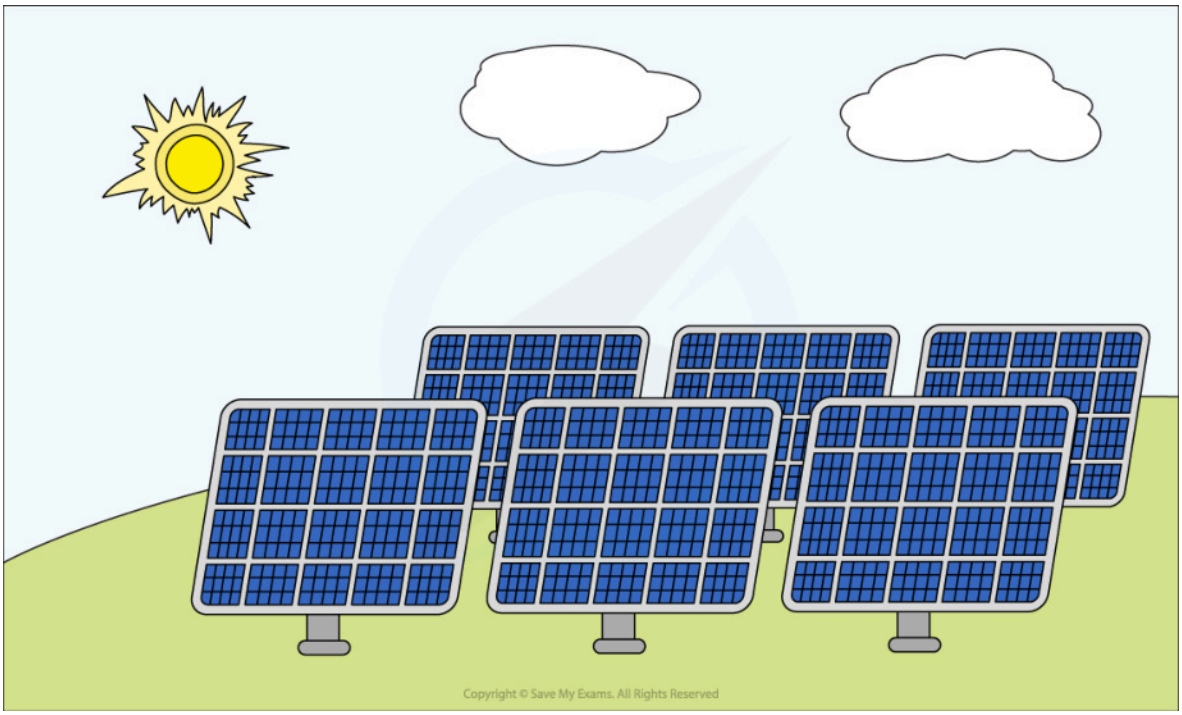
- No greenhouse gas emissions or air pollutants produced during operation
- Suitable for various scales of application (from house rooftops to very large solar farms)
- Can be integrated into existing buildings and infrastructure
- Solar is progressively becoming less expensive and more efficient
- Solar 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)



Solar PV panels use energy from sunlight to produce electricity

Tidal energy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- 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

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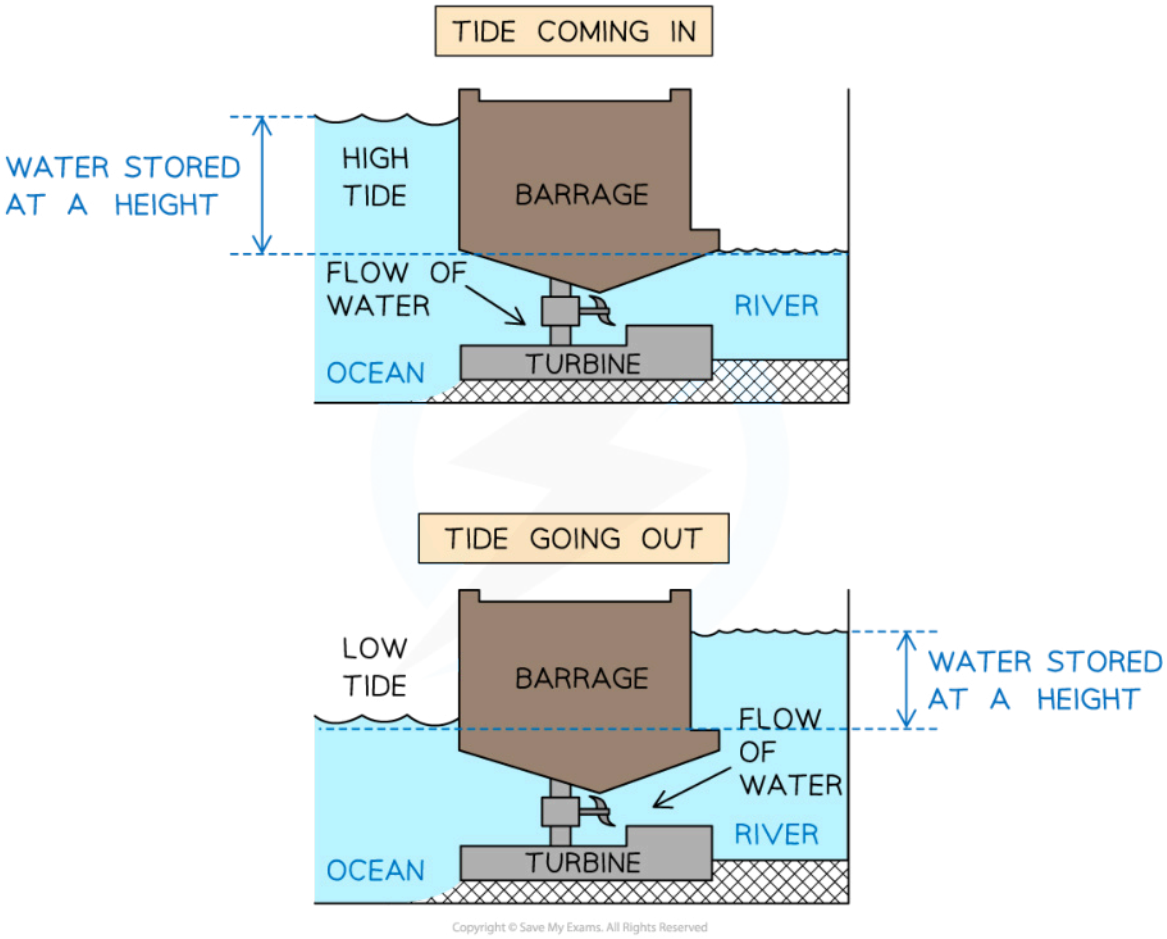

Tidal barrages can generate electricity from the movement of water, both as the tide comes in and as it goes out again

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


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- 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

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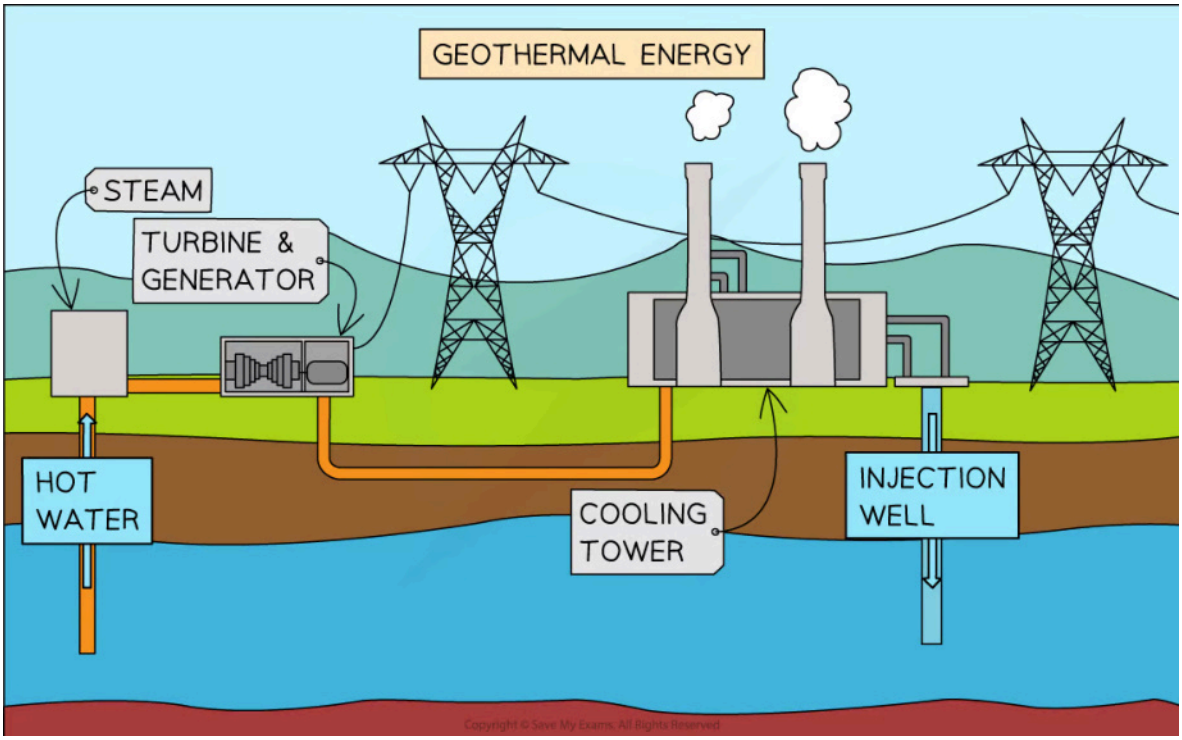

Cold water is heated by natural geothermal energy underground and then returned as hot water or steam, which can be used to generate electricity

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

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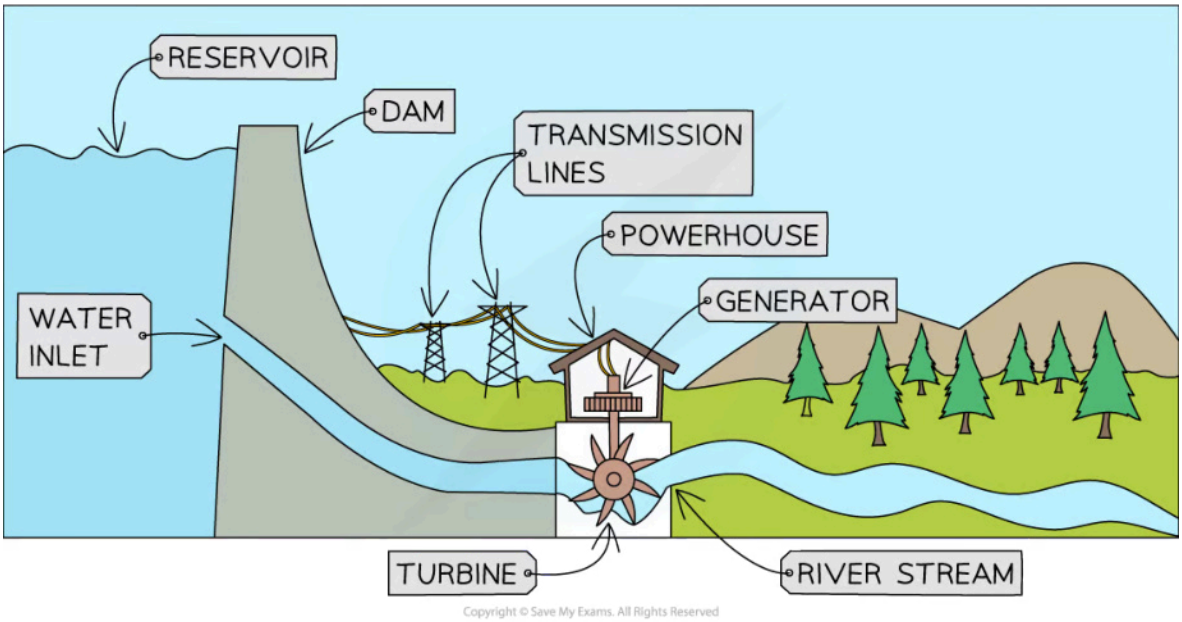

A hydroelectric dam transfers the gravitational potential energy of the water to kinetic energy in order to generate electricity

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**

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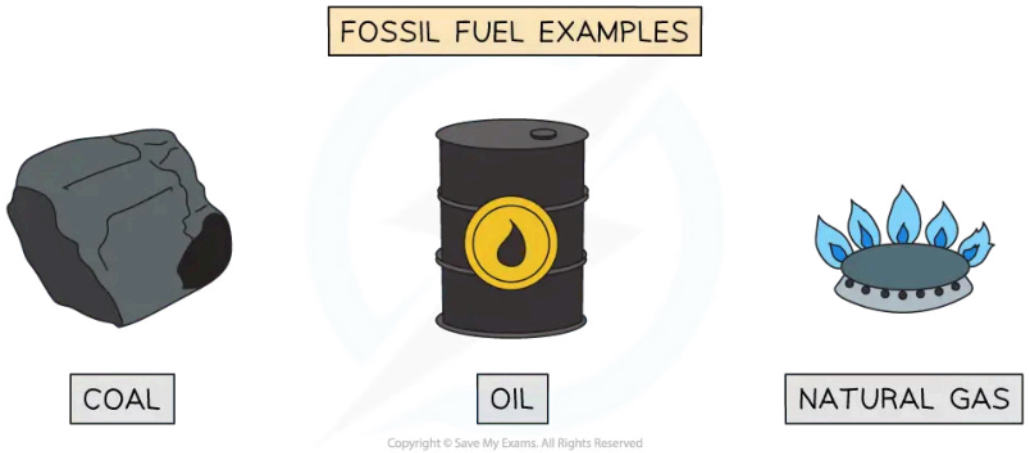
- Energy from the sun was transferred to chemical energy stores within plants through photosynthesis (plants use energy from sunlight to make food)
- Animals ate the plants and the energy was then transferred to their chemical store



Fossil fuels include coal, oil and natural gas

- **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


Your notes

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

EXAM TIP

Make sure you can discuss the relative sustainability of different energy sources with examples.

Your notes

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


Your notes

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

EXAM TIP

Don't just assume renewable energy is always 'green'. Remember that the sustainability of renewable energy devices also depends on the materials used in their production; e.g. mining for rare earth elements and recycling challenges can make renewable energy less sustainable than it first appears.

Your notes

Energy Consumption & Choices

Your notes

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

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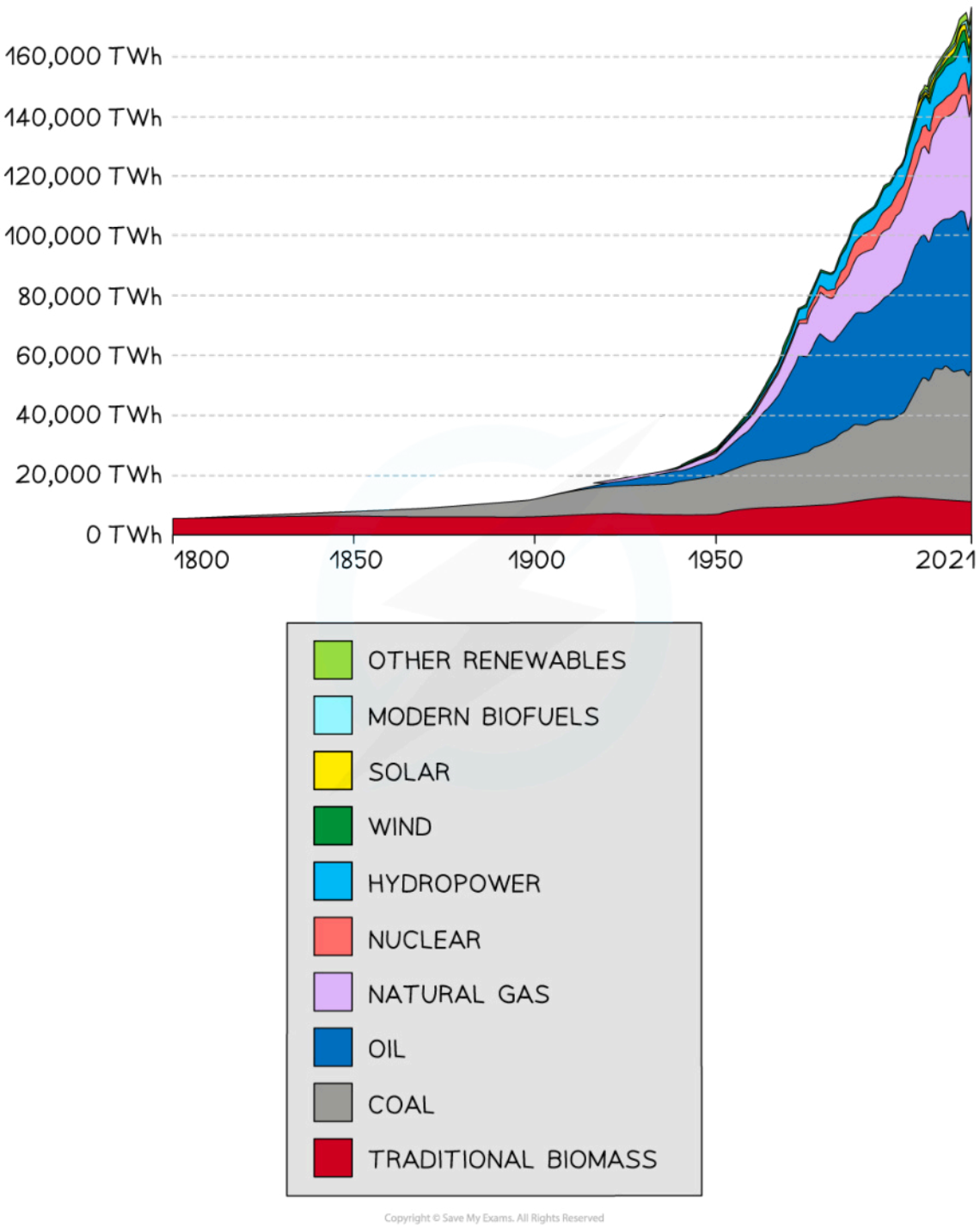

Global annual energy consumption measured in terawatt-hours

Energy production and consumption changes


Your notes

- 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

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    - 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

EXAM TIP

In an exam, don't assume that renewable energy can easily replace fossil fuels in all industries, especially those like steel and concrete production.

Be clear on energy efficiency vs. reducing consumption: these are different concepts; efficiency

involves using less energy for the same task, while reducing consumption means using energy less often or at lower levels.


Your notes

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

EXAM TIP

Don't confuse energy security (ability to meet demand reliably) with availability (what resources are present in the country). A country might have abundant resources (availability) but still struggle to meet its energy needs reliably (energy security) if it lacks the proper systems, funding, or stable supply chains.

Your notes

Energy Storage & Conservation

Your notes

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

Your notes

- **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

Awaiting image: Pumped hydroelectricity storage

Image caption: Pumped hydroelectricity storage

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


Your notes

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


Your notes

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)

EXAM TIP

Remember that energy conservation focuses on behaviour change, while energy efficiency focuses on technology and design improvements. Energy efficiency practices can be used and implemented to achieve energy conservation.

Your notes