Edexcel Geography A-level

The Carbon Cycle and Energy Security

Detailed Notes

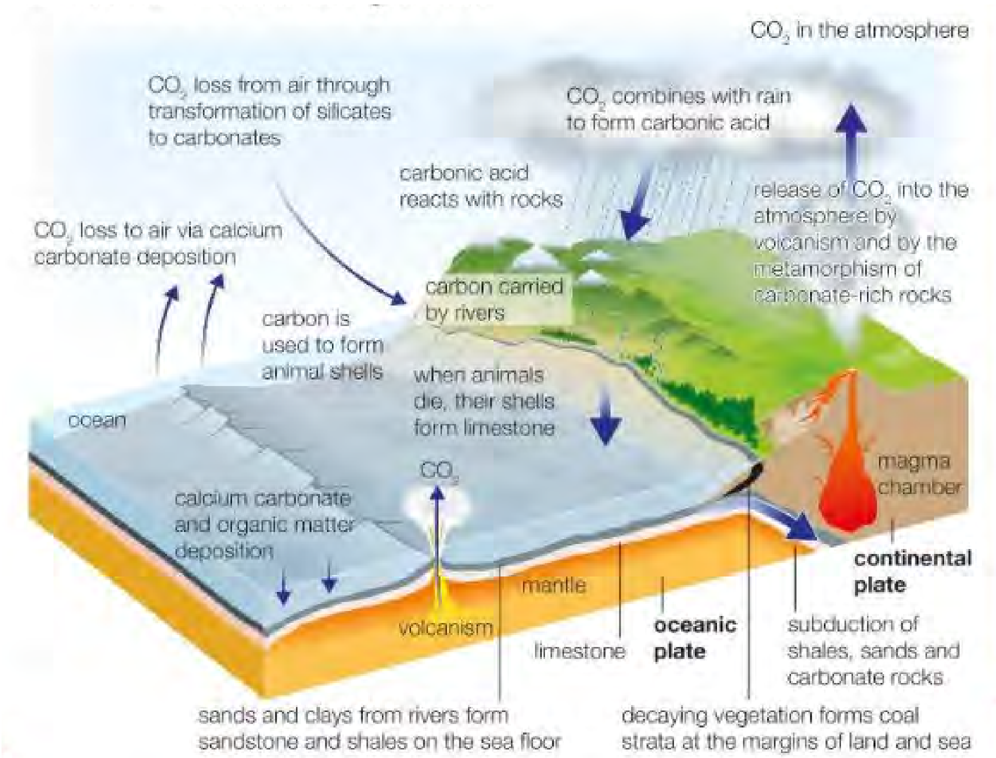
The Geological Carbon Cycle

The **natural carbon cycle** is the movement and storage of carbon between the **land**, **ocean** and the **atmosphere**.

There are three forms of carbon in the Carbon Cycle:

- **Inorganic** – Found in rocks as bicarbonates and carbonates
- **Organic** – Found in plant material and living organisms
- **Gaseous** – Found as CO_2 and CH_4 (methane)

There is generally a **balance** between production and absorption (or sources and sinks) of carbon in the natural carbon cycle. Sometimes, it takes a long time for **equilibrium** to be reached e.g. after a volcanic eruption.



Stores are terrestrial, oceanic or atmospheric. **Fluxes** refer to the movement/transfer of carbon between stores.

Stores of Carbon Cycle

A **carbon sink** is any store which **takes in more carbon than it emits**, so an **intact tropical rainforest** is an example. A **carbon source** is any store that **emits more carbon than it stores** so a **damaged tropical rainforest** is an example.

Carbon is present in **stores** of:

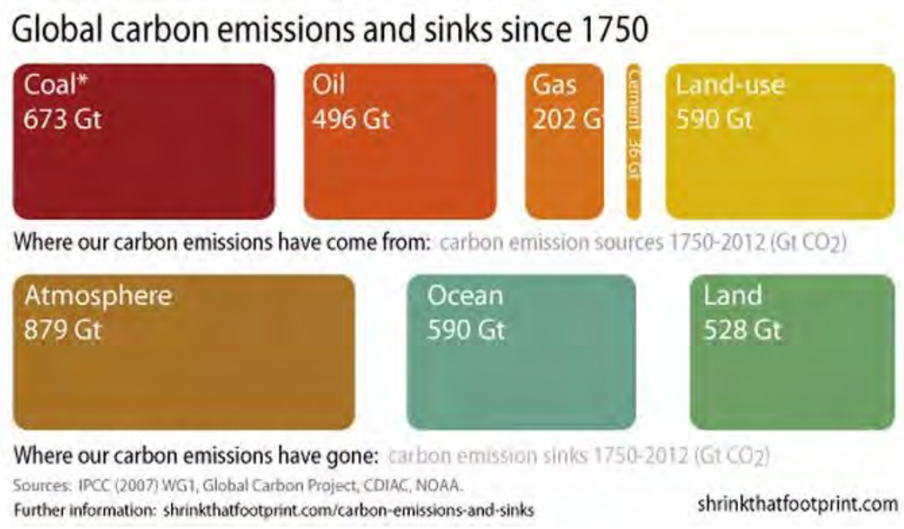
- The **atmosphere** as CO_2 and methane
- The **hydrosphere** as **dissolved CO_2**
- The **lithosphere** as **carbonates** in limestone and fossil fuels like coal, gas and oil
- The **biosphere** in living and dead organisms

Carbon Sequestration is the transfer of carbon from the atmosphere to other stores and can be both **natural and artificial.** For example. a plant sequesters carbon when it photosynthesises and stores the carbon in its mass.

Main Carbon Stores (In order of magnitude):

- **Marine Sediments and Sedimentary Rocks** - Lithosphere - Long-term
    - Easily the biggest store. **66,000 - 100,000 million billion metric tons of carbon**. The rock cycle and continental drift recycle the rock over time, but this may take thousands, if not millions of years.
- **Oceans** - Hydrosphere - Dynamic
    - The second biggest store contains a tiny fraction of the carbon of the largest store. **38,000 billion metric tons of carbon**. The carbon is constantly being utilised by marine organisms, lost as an output to the lithosphere, or gains as an input from rivers and erosion.
- **Fossil Fuel Deposits** - Lithosphere - Long-term but currently dynamic
    - Fossil fuel deposits used to be rarely changing over short periods of time, but humans have developed technology to exploit them rapidly, though **4000 billion metric tons of carbon** remain as fossil fuels.
- **Soil Organic Matter** - Lithosphere - Mid-term
    - The soil can store carbon for over a hundred years, but deforestation, agriculture and land use change are affecting this store. **1500 billion metric tons of carbon** stored.
- **Atmosphere** - Dynamic
    - Human activity has caused CO_2 levels in the atmosphere to increase by around **40% since the industrial revolution**, causing unprecedented change to the global climate. **750 billion metric tons of carbon** stored.
- **Terrestrial Plants** - Biosphere - Mid-term but very dynamic
    - Vulnerable to climate change and deforestation and as a result carbon storage in forests is declining annually in some areas of the world. **560 billion metric tons of carbon.**

The **lithosphere** is the **main store of carbon**, with global stores **unevenly distributed**. For example, the **oceans are larger** in the **southern hemisphere**, and **storage in the biosphere** mostly occurs on land. **Terrestrial plant storage** is focussed in the **tropics** and the **northern hemisphere**.



Fluxes of Carbon Cycle

The **transfers in the carbon cycle** act to **drive and cause changes** in the carbon cycle over time. They all have **impacts of varying magnitude over different lengths of time**. **Biological and chemical processes** determine how much carbon is stored and released. The role of living organisms is very important in maintaining the system running efficiently.

Photosynthesis - Living organisms convert **Carbon Dioxide** from the atmosphere and **Water** from the soil, into **Oxygen** and **Glucose** using **Light Energy**. By removing CO_2 from the atmosphere, plants are **sequestering carbon (see below)** and reducing the potential impacts of climate change. The process of **photosynthesis** occurs when **chlorophyll** in the leaves of the plant react with CO_2, to create the **carbohydrate glucose**. Photosynthesis helps to maintain the balance between oxygen and CO_2 in the atmosphere. The formula is shown below:

Carbon Dioxide + Water → *Light Energy* → Oxygen + Glucose

Respiration - Respiration occurs when plants and animals **convert oxygen and glucose into energy** which then produces the **waste products of water and CO_2**. It is therefore chemically the opposite of photosynthesis:

Oxygen + Glucose → Carbon Dioxide + Water

During the day, plants photosynthesise, absorbing significantly more CO_2 than they emit from respiration. During the night they **do not photosynthesise** but they do **respire,** releasing more CO_2 than they absorb. Overall, plants absorb more CO_2 than they emit, so are **net carbon dioxide absorbers** (from the atmosphere) and **net oxygen producers** (to the atmosphere).

Combustion - When fossil fuels and organic matter such as trees are burnt, they **emit CO_2 into the atmosphere**, that was previously locked inside of them. This may occur when **fossil fuels are burnt to produce energy**, or if wildfires occur.

Decomposition - When living organisms die, they are **broken down by decomposers** (such as **bacteria and detritivores**) which **respire**, returning CO_2 into the atmosphere. Some **organic matter** is also **returned to the soil** where it is stored adding carbon matter to the soil.

Diffusion - The **oceans can absorb CO_2** from the atmosphere, which has **increased ocean acidity by 30% since pre-industrial times**. The ocean is the biggest carbon store, but with carbon levels increasing seawater becomes more acidic which is harming aquatic life by causing **coral bleaching.** Many of the **world's coral reefs now under threat**.

Sedimentation - This can happen on land or in the sea. For example, when shelled marine organisms die, their shell fragments fall to the ocean floor and become **compacted over time** to form **limestone. Organic matter** from **vegetation and decaying marine organisms** is compacted over time, whether on land or in the sea, to form **fossil fuel deposits**.

Weathering and Erosion - Inorganic carbon is released slowly through **weathering**: rocks are eroded on land or broken down by **carbonation weathering**. Carbonation weathering occurs when CO_2 in the air mixes with rainwater to create **carbonic acid** which **aids erosion of rocks such as limestone**. The carbon is moved through the water cycle and enters the oceans. **Marine organisms use the carbon in the water to build their shells**. Increasing carbon dioxide levels in the atmosphere, may **increase weathering and erosion as a result, potentially affecting other parts of the carbon cycle**.

Metamorphosis – Extreme heat and pressure forms metamorphic rock, during which some carbon is released and some becomes trapped.

Volcanic outgassing - There are pockets of CO_2 found in the Earth's crust. During a volcanic eruption or from a fissure in the Earth's crust, this CO_2 can be released.

Variations In Carbon Fluxes

The quickest cycle is completed in seconds as plants absorb carbon for **photosynthesis** and then they release carbon when they **respire**. This cycle can slow down when levels of light or CO_2 drop.

Dead organic material in soil may hold carbon for hundreds of years. Some organic materials may become buried so deeply that they don't decay, or are buried in conditions unfavourable to **decayers** (potent low-lying gas, too much water). This material will become **sedimentary rocks** or **hydrocarbons** by geological processes.

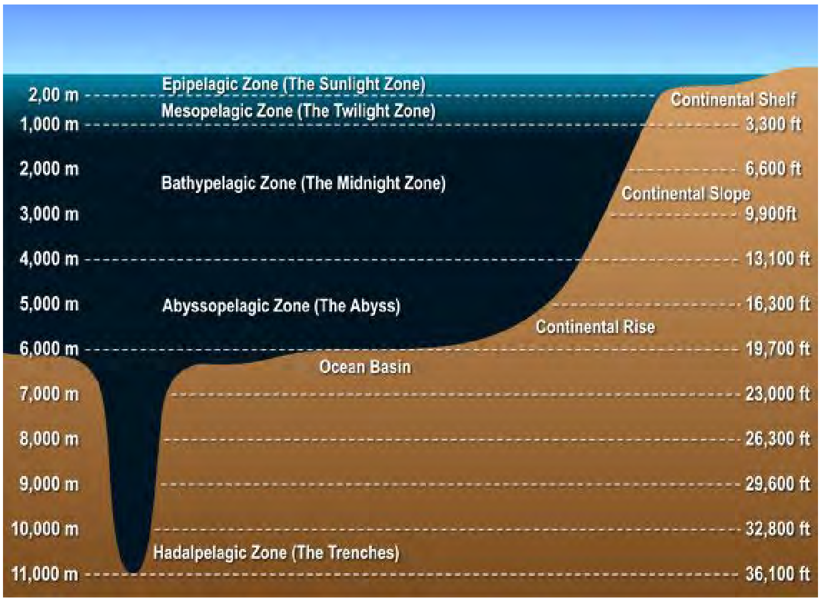
Complex Carbon Processes

Oceans are the **largest carbon stores**; they are 50 times larger than the atmosphere with 93% of CO_2 stored in oceanic algae, plants and coral. Lots of processes occur simultaneously within the ocean to store these large amounts of CO_2. This transfer of CO_2 into the sea is called **ocean sequestration**.

Small changes in oceanic carbon levels can have **significant global impacts**. The CO_2 gas exchange between the atmosphere and ocean operate on different timescales.

It is important to note that the ocean has **different layers**, as shown in the diagram below.

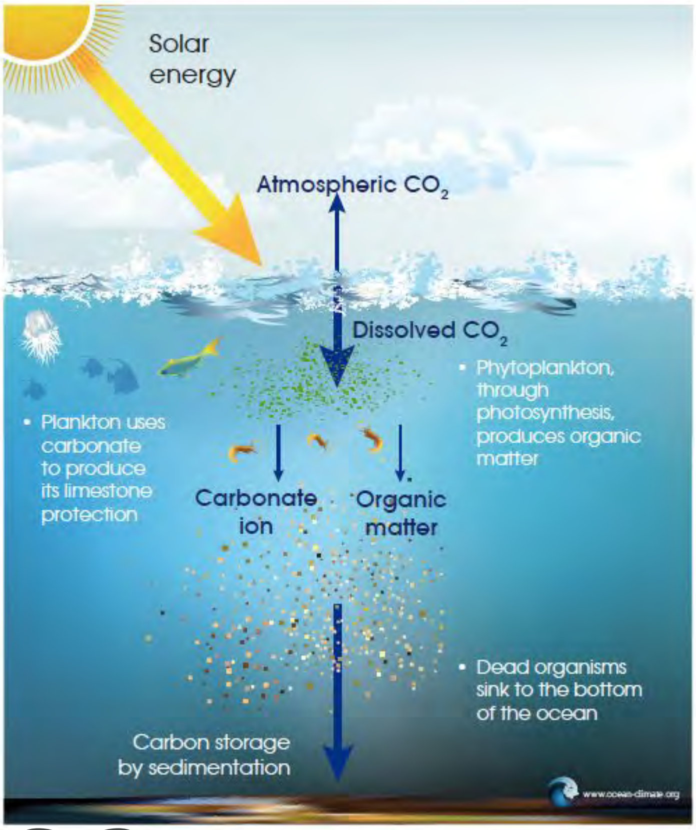
The majority of the processes which take the CO_2 out of the atmosphere and into the ocean occur in the **top surface layer** which makes up only a small proportion of the water in the world's ocean. The carbon rich water in the surface layer is then transferred down into the lower layers of the ocean and transported around the world due to **thermohaline circulation.** It is this circulation which allows such large amounts of carbon to be stored in the sea.



The Biological Carbon Pump

Phytoplankton are microscopic organisms that, like plants, **photosynthesise**. They take in carbon and turn it into organic matter. As they are the base of the marine food web (half of the planet's **biomass** consist of phytoplankton despite their microscopic size) when they get eaten, carbon is passed through the **food chain.** Remember that CO_2 is also released back into the water as these organisms respire.

Some organisms like Plankton sequester CO_2, turning the carbon into their hard outer shells and inner skeletons. When these organisms



die, some of their shells **dissolve** into the ocean water meaning the carbon becomes part of **deep ocean currents**. Any dead organisms which sink to the seafloor become buried and compressed, eventually forming **limestone** sediments (**sedimentation**). Over a long time period these can turn into fossil fuels.

At the same time, some CO_2 from the atmosphere will naturally by **dissolving** into the water. This process occurs on the surface of the oceans where CO_2 reacts with water to form **carbonic acid**. As the concentrations of CO_2 in the atmosphere increase, oceans absorb more CO_2 causing them to become more acidic. This **acidification of the oceans** could have long lasting negative effects. This movement of CO_2 isn't one way, some will go from the water back into the atmosphere.

The Physical Pump

There would come a point where the surface layer of the ocean would become so saturated with carbon that this process would slow down or stop occurring. (If you add salt to a cup of water there is a finite amount of salt which can be dissolved into the water).

However, **oceanic circulation** provides a constant source of new water on the surface while transferring surface water into the deep ocean. It is this process which enables the ocean to store so much carbon. Water is not stored evenly within the water; the colder the water, the more CO_2 is absorbed so the concentration of CO_2 in the ocean is different around the world.

- CO_2 concentration is 10% higher in the **deep ocean** compared to the surface of the ocean.
- **Polar regions** hold more carbon than tropical regions.
- Warm tropical waters **release** CO_2 to the atmosphere but cold high latitude oceans **absorb** in CO_2 from the atmosphere.

Thermohaline Circulation

Thermohaline circulation is an ocean current that produces both **vertical** and **horizontal** circulation of cold and warm water around the world's oceans. In addition to this, the atmospheric circulation creates large currents in the oceans which transfers water from the warmer tropical areas of the world to the colder polar regions.

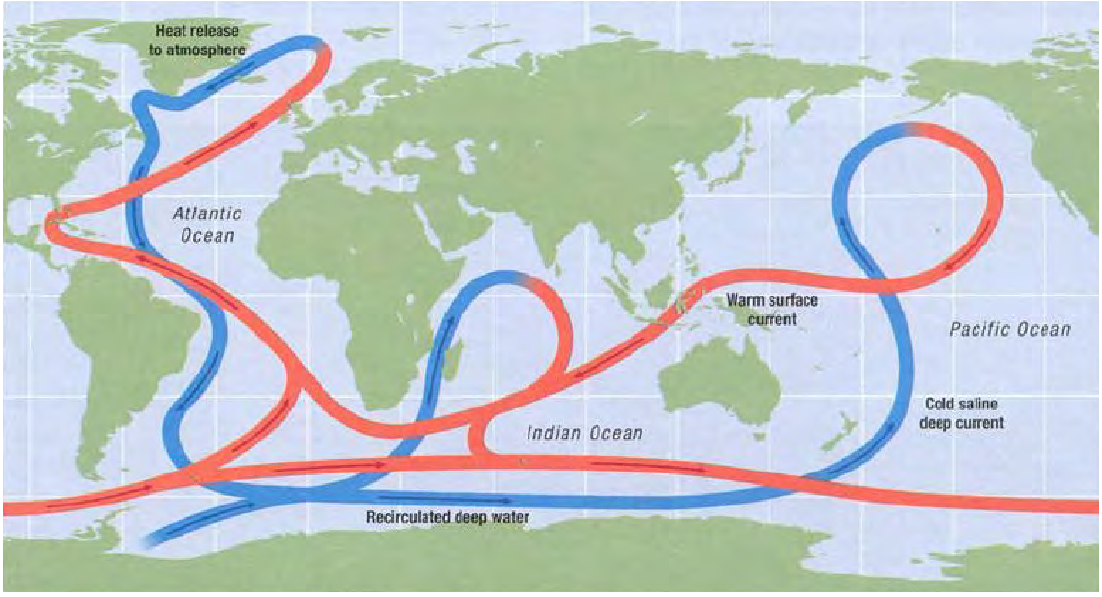
The rate of circulation is **slow**; it takes around **1000 years** for any cubic metre of water to travel around the entire system. Warm surface waters are **depleted of CO_2 and nutrients** therefore the foundation of the planet's food chain depends on cool and nutrient rich water which support algae to grow.

Water in the North Atlantic is **cold** and very **saline** which means it is denser and heavier causing it to sink. When the cold water sinks, warm water is drawn from the ocean surface. Eventually cold water is drawn from the bottom of the ocean and then warmed up.

The process in more detail:

1) The main current begins in **polar oceans** where the water is very cold, surrounding seawater sinks due to a **higher density**.
2) The current is **recharged** as it passes Antarctica by extra cold, salty, dense water.
3) **Division** of the main current; northward into the Indian Ocean and into the Western Pacific.

4) The two branches warm and rise as they travel northward then loop back southward and westward.
5) The now warmed surface waters continue **circulating** around the globe. On their eventual return to the North Atlantic they cool and the cycle begins again.



Source: www.researchgate.net

The rate of **absorption** of CO_2 into the ocean depends on **ocean temperatures**. The colder the water, the more CO_2 is absorbed. Therefore, as ocean temperatures increase, the oceans will **absorb less CO_2** (possibly even emitting some of its stored carbon dioxide). This would **accelerate Climate Change** and lead to further ocean warming (**positive feedback mechanism**).

The role of the oceans in **regulating climate** and **greenhouse gas emissions** is essential to the Earth!

Terrestrial Sequestration

Primary producers sequester carbon through the process of **photosynthesis**. All living things either release or intake carbon.

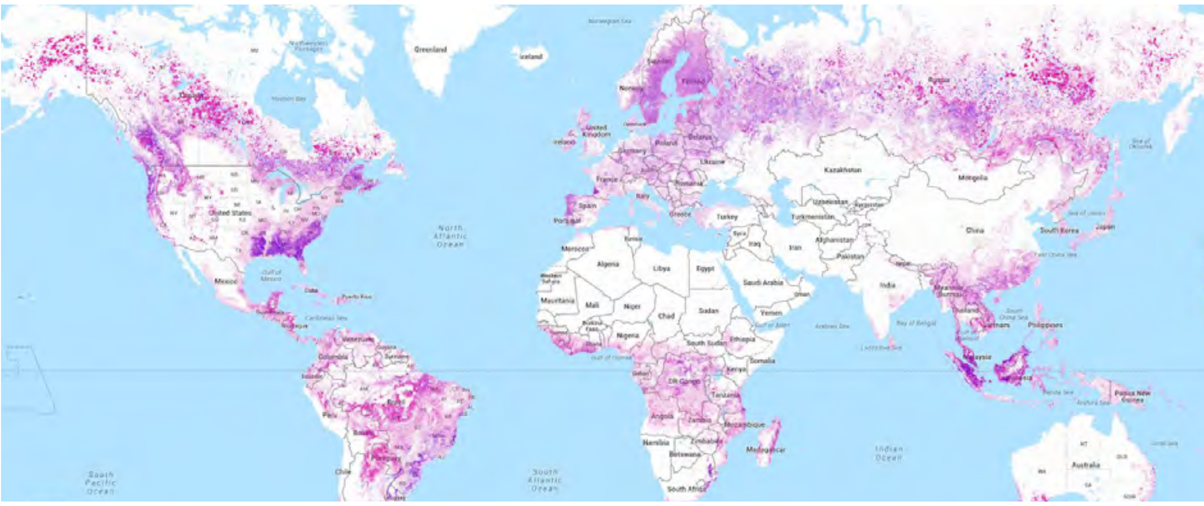
- **Primary producers** (plants) take carbon from the atmosphere to **photosynthesise** and release carbon when they respire.
- Vegetation growth depends on **water, nutrients** and **sunlight**.
- When **consumers** eat plants, carbon from the plants is converted into **fats** and **proteins**.

- **Micro-organisms** feed on waste material from animals and plants.
- Animal and plant remains are easier to decompose compared to wood. **Decomposition** is faster in tropical climates with high rainfall, temperatures and oxygen levels.
- **95%** of a tree's **biomass** consists of CO_2 which is sequestered and converted to cellulose. The amount of carbon stored in trees depends on the balance of respiration and photosynthesis.

Carbon fluxes due to terrestrial organisms vary:

- **Diurnally** – during the day, fluxes are **positive** from the atmosphere to the ecosystem where as in the night, fluxes are **negative** from the atmosphere to the ecosystem.
- **Seasonally** – In the **northern hemisphere** during **winter**, plants die and decay leading to high atmospheric CO_2 concentrations but during **spring** when plants begin to grow, CO_2 levels in the atmosphere begin to drop.

Different amounts of carbon are stored worldwide and one of the stores that is currently changing is trees:



Key: **Pink is forest area lost. Purple is forest area gained.** Source: Global Forest Watch

The map shows how **forests are declining in the tropical areas** in the **southern hemisphere** and **growing in the northern hemisphere**. This is supported by data which shows that tropical areas such as Brazil and Indonesia have seen a **decrease in carbon stocks of around 5 Gigatons of Carbon (GtC) in the last 25 years**, but Russia, USA and China have seen **increases of around 0.3, 2.9 and 2.3 GtC** respectively. Detailed information on forests and climate change shows that:

- **Non-tropical forests** have seen an **increase in carbon sequestration in recent years**, especially in Europe and Eastern Asia, due to **conversion of agricultural land and plantations to new forests.**
- **Forests in industrialised regions** are **expected to increase by 2050** but in the global south, forested areas will decrease.
- **Rate of forest loss has decreased** from 9.5 million hectares per year in the 1990's to 5.5 million hectares per year in 2010-15.
- The eight countries with the largest forested areas are: Russia, Brazil, China, Canada, USA, DRC, Australia and Indonesia.
- **Brazil has the most carbon stored on land and the most extensive deforested area.**
- **China has the largest amount of afforested area.**
- **Net Primary Productivity (NPP)** refers to the amount of carbon absorbed by forests. For tropical forests it is positive all year round, but deciduous forests, have a negative NPP in winter, but across the whole year their NPP is positive.

Soil's Capacity to Store Carbon

Soils store between **20-30%** of the world's carbon. The amount of CO_2 sequestered or emitted depends on **local conditions**.

In **arid and semi-arid** soils are the most important store. Any loss by a plant to the ground means that some carbon will transfer to the soil. Soil **microbes** break down plants release carbon to the atmosphere. After organisms die, thousands of compounds in soil are **decomposed**.

The most long-term process is the formation of **Humus**, it has a dark and rich colour and 60% of it contains carbon.

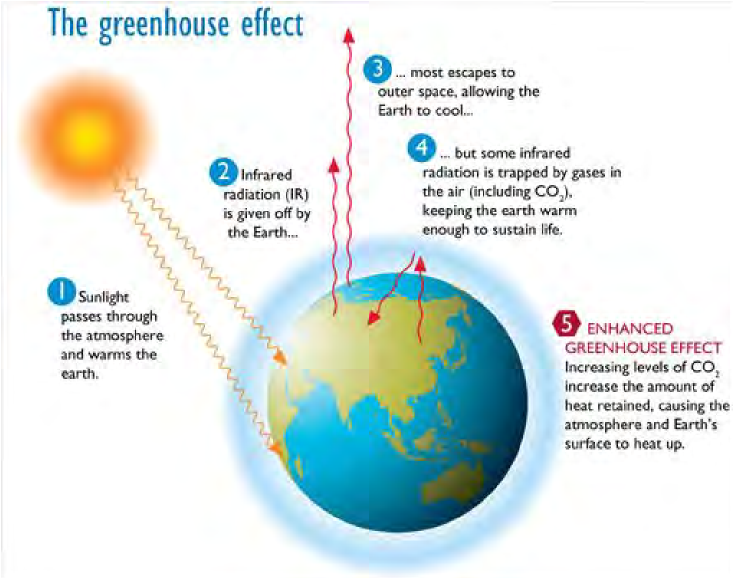
Factors affecting soil capacity to store organic carbon include:

- **Climate** – this affects the **rate of plant growth** and **microbial activity**. Decomposition occurs at a fast rate in places with higher temperatures and rainfall.
- **Soil type** – **Clay** rich soils contain more carbon than **sandy** soils.
- **Use of soils** – Land use, **cultivation** and disturbance can affect how much carbon can be held.

If **plant residue** is added to the soil at faster rate than soil organisms can convert it to CO_2, carbon will eventually be removed from the atmosphere and **sequestered in the soil**.

The Natural Greenhouse Effect

Earth has a temperature control system which relies on **greenhouse** gases in the atmosphere. The Earth's **climate** is driven by incoming **shortwave solar radiation:**



Source: www.geocoops.com

- Around **31%** of carbon is **reflected** by clouds and gases in the atmosphere.
- The remaining **69%** is **absorbed** by the Earth's surface and oceans.
- **69%** of surface absorption is **reradiated** to space as longwave radiation
- A large proportion of longwave radiation is radiated back to the Earth by clouds & greenhouse gases

Constant levels of CO_2 help to maintain **stable average temperatures** worldwide. Before The Industrial Revolution, the natural greenhouse effect was constant.

- The **slow carbon cycle, volcanism, sedimentation** have been fairly constant over the last few centuries.
- Natural exchanges between the slow and fast sections of the carbon cycle were relatively small.
- There were **small variations** in atmospheric CO_2 up until the late 19^{th} century.

Anthropogenic Interference

A balanced carbon cycle is very important in maintaining other global systems.

The Enhanced Greenhouse Effect

Since the 1750s (when industrialisation began in the UK), global concentrations of **greenhouse gases** like CO_2 & CH_4 have increased by more than **25%.** Since the 1980s, **75%** of carbon emissions have come from **burning fossil fuels**.

Human activities have led to more carbon being released into the atmosphere and less being absorbed:

- **Land Use Change:** Accounts for a **tenth of carbon release annually** and impacts on **short-term stores** in the carbon cycle, such as the soil and atmosphere. For example:
    - **Farming Practices:** In the Amazon, around **70% of deforestation is for cattle ranching**. Cattle produce significant amounts of **methane**, further contributing to global warming. Scientists are considering whether feeding cows different foods would help to reduce their methane emissions.
- **Fertilisers** are a significant source of greenhouse gases as well as **rice padi fields**, from which methane emissions have increased as a result of **increased productivity** due to higher CO_2 levels. More sustainable grains and seeds like **quinoa** are being considered as substitutes, which require **less water to grow**.

- **Deforestation:** In total, **deforestation accounts for about 20% of all global greenhouse emissions**. The main impact is when the cycle is interrupted and the land is used for other purposes, which then reduces carbon sequestration and land becomes a **carbon source** rather than a **carbon sink**.

- **Urbanisation:** This is the process of **replacing countryside with buildings and other similar infrastructure**. It affects the **local and global carbon cycles**, by replacing vegetation and covering soils. **Urban areas occupy 2% of the world's land mass**, but these areas **account for 97% of all human caused global CO_2 emissions**. Cement is an important building material, but releases carbon dioxide during production, contributing **7% to global carbon dioxide emissions each year**, so sustainable options for recycling concrete are being developed.

- **Combustion of Fossil Fuels**: This results in **CO_2, sulphur and particulates** being released into the atmosphere. If combustion occurs in a hot engine, **NO_2** will also be released (also a greenhouse gas) as nitrogen from the air fuses with oxygen.

The amount of carbon is measured in **gigatonnes** (Gt) or **petagrams** (Pt). It is estimated that burning fossil fuels has added more than **180 Gt** of carbon to the atmosphere.

Increasing levels of greenhouse gases can affect the **planet's climate**, which can have implications for the water cycle, biomes and wildlife living on Earth.

Implications of The Enhanced Greenhouse Effect

Temperature

The amount of **solar energy** reaching the Earth varies depending on location, and is the main factor in determining climate temperatures. **Solar intensity** is more intense at the equator, and reduces as you travel towards the poles.
The **Albedo Effect** will also determine the temperature of a location. Snow **reflects** solar radiation whereas dark forests **absorb** the most solar radiation.

Climate

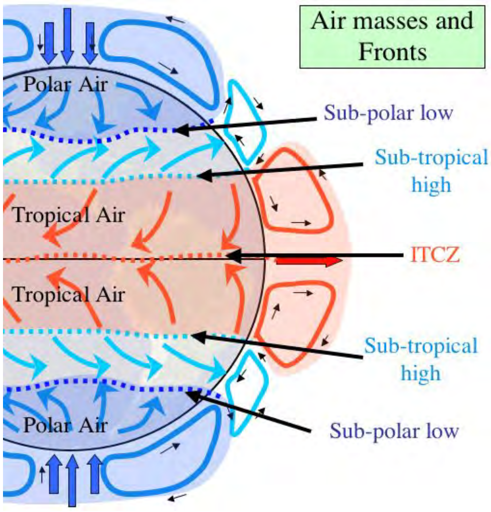
Rising levels of CO_2 in the atmosphere are believed to be the main contributor to an increase in **average global temperatures**.
However, increases may vary:

- In Europe, average temperatures are expected to increase more than the global average.

- The largest increases are expected in Eastern and Northern Europe during winter and Southern Europe during summer.
- Annual precipitation is expected to increase in Northern Europe but decrease in Southern Europe.
- Extreme weather events are likely to increase in both frequency and intensity.

Precipitation

Solar radiation is the most intense along the equator, so **convectional rainfall** is common and rainfall is generally very high.



Where **convectional rainfall** is likely to occur can be understood using the **ITCZ Model**.

Rainfall occurs at **subtropical highs** (mid-latitude) and the **poles**.

Where air submerges and cools, water vapour condenses to form clouds and precipitation. Where air rises, the air heats up and moisture will evaporate. This creates dry weather conditions.

Source: montessourimuddle.org

Ecosystems

Ecosystems help to regulate the carbon and hydrological cycles. **Global Warming** could impact the functioning of ecosystems. The two **biomes** most at risk are **the Artic** and the **coral ecosystems.**

Species with low population numbers are already at **high risk**. There is already evidence showing that there will be change in species' population size, timing of reproduction and migration.

Marine organisms are also at risk. They are threatened with **low oxygen levels** and high rates of **acidification**. The impact on coastal ecosystems and low lying areas of **sea levels rising** could continue.

The arctic region is warming twice as fast as the global average. **Melting permafrost** releases methane and carbon dioxide which increases the concentration of greenhouse gases in the atmosphere. This could lead to further **Global Warming** and even more melting of snow and ice, establishing a **positive feedback loop**.

The **Arctic tundra** ecosystem has changed significantly; rapid warming has contributed to extensive melting of snow and ice during the summer months. Shrubs and trees which previously couldn't live in the Arctic have began to grow. In Alaska, the **Red Fox** has now spread northwards and competes with the Arctic Fox for food and territory.

Not all scientists agree that permafrost melting will release CO_2 and CH_4. Some studies show that when permafrost melts, the **carbon may remain** in the soil and warmer temperatures lead to **more decomposition** which uses CO_2

Hydrological Cycle

- Increased rate of **evaporation** could lead to more moisture being held in the atmosphere rather than in the ocean.
- Increase in surface **permafrost temperatures**.
- Less sea ice and glacier storage.
- Change in **capacity** of terrestrial ecosystems.
- Change in **river discharge** - increased risk of flooding in winter and droughts in summer.

Energy Security

Maximum energy security refers to the **uninterrupted availability** of energy sources at an **affordable price**.

> **Long term energy security** mainly deals with timely investments to supply in energy sources that will match economic developments and environmental needs.
> **Short term energy security** focuses on the ability of the energy system to react promptly to sudden changed in the balance between energy demand and energy supply.

There are several key points worth remembering about **energy security**:

- It is generally evaluated at a **national level**, countries are either energy secure or insecure.
- There are four aspects of supply: **Availability, Accessibility, Affordability and Reliability.**
- It requires an accurate **prediction** of future energy.
- Those countries that are most energy secure are those who can **meet their energy demand** using supply from **within their boundaries**.

A **good quality energy supply** is **consistent and secure** and can be **relied upon** year round. There is unlikely to be any **geopolitical problems** and there is little risk from changing **climatic conditions** or **natural hazards**. A good quality energy supply involves **different sources** which contribute to the energy mix.

Energy security is important for the **functioning of the country** and particularly its **economy**, including the operation of:

- Most modes of **transport**
- **Lights** in towns and cities
- **Heating** homes
- Domestic appliances
- Necessary for most forms of **manufacturing**

Measuring Energy Usage

Energy consumption is usually measured **per capita** (per person) using on the following measures:

- Equivalent kilograms of oil per year (Kgoe/yr)
- Gigajoules per year (GJ/yr) or Exajoules (EJ/yr)
- Megawatt hours per year (Mwh/yr)

Energy Intensity is an alternative measure of how **efficiently** a country is using its energy, in units of energy used per unit of GDP. A **high energy intensity** indicates a **high price** or cost of converting energy into GDP. It is generally recognised that **energy intensity decreases with development**; energy is used more efficiently and so the cost per unit of GDP reduces.

Energy Mix

The **energy mix** refers to the **range and proportion** of energy produced by methods of production. These can include:

- **Non-renewable fossil fuels** like oil, gas and coal.
- **Recyclable fuels** like nuclear energy and general waste.
- **Renewable energy** like wind, solar and geothermal.

The **global energy mix** is **dominated by fossil fuels**. **Primary energy** sources produce energy by using a **raw material**, whereas **secondary sources** are **modified primary energy sources** which are easier to use e.g. oil into petrol and coal into electricity.

Primary Energy Sources:

Coal: Accounts for 27% of global energy production. Usage is **decreasing** as China shifts its energy mix away from coal and less polluting energy sources are used. Most production occurring in China, ahead of the USA and India.

Petroleum (Oil): Accounts for 32% of global energy production. Usage is still **increasing** as global energy demand increases. Most usage in USA, China and India and greatest production in the USA, Saudi Arabia and Russia

Natural Gas: With only 50% of the carbon emissions of coal and accounts for 22% of global energy production, which is **increasing** year on year. Highest production in USA, Russia and Iran and greatest consumption in USA, Russia and China.

Uranium - Has a very low carbon footprint that accounts for around 4% of global energy production, with most production in Kazakhstan and greatest amount of nuclear fission energy produced in the USA. Production likely to **increase** in future.

Biomass (May also be secondary): In many LIC's biomass is burned to produce energy. Burning organic matter such as wood is very inefficient. However biomass produces a large proportion of energy in LIC's, though it makes up a low proportion of worldwide energy consumption. In HIC countries, biomass is being used more efficiently to produce energy, such as in biodiesel. Overall **decrease** in use on a global scale.

Hydroelectric Power (HEP): Water drives turbines to produce electricity and is **very efficient**. Hydropower has been used for many years as a **renewable energy**, but only accounts for a small percentage of global energy production. Expected to **increase** globally, but with decreases in some HIC's.

Solar: Solar energy usage is **increasing** rapidly year on year as the technologies for solar power become cheaper. China has the largest installed capacity, though production is much lower due to climatic conditions. Growth in LIC countries as technology becomes cheaper.

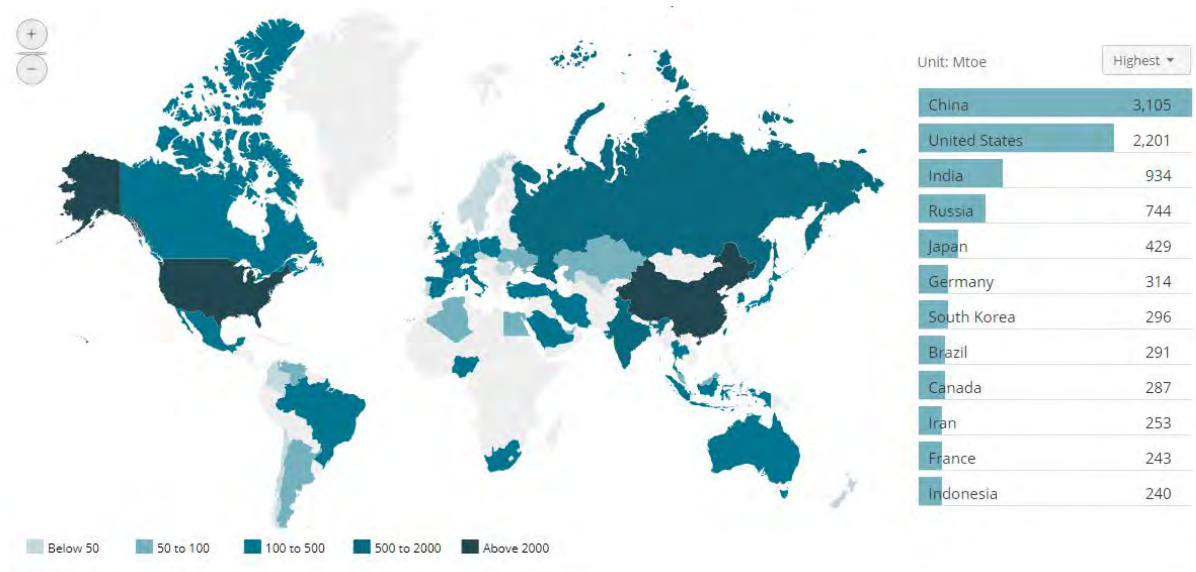
Wind: Other than hydropower and biomass, produces the most energy of renewable sources, with greatest production and capacity in China. Technology is also spreading to LIC countries and offshore is **increasing** too.

Wave: Very low generation, though **technology is developing** and a similar trend may be seen to that of solar and wind when the technology becomes cheaper.

Tidal: So expensive that there is currently only a handful of installed tidal power schemes on a global scale. The Swansea bay scheme was abandoned due to the potential costs that it would induce. One successful project may lead to a multiplier effect.

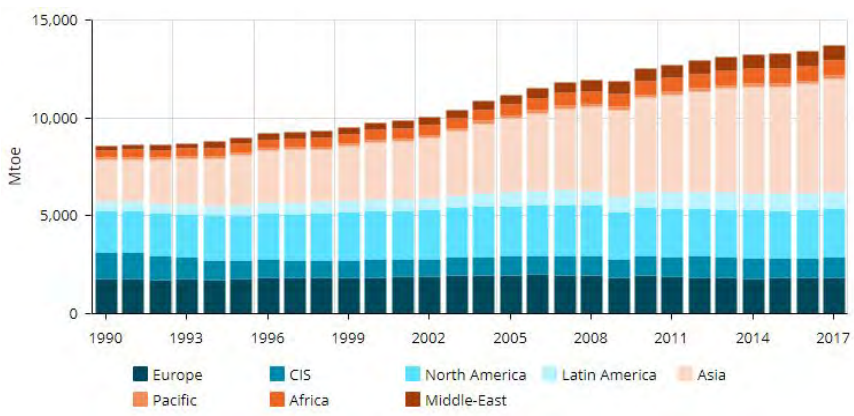
Geothermal Energy: Very efficient and reliable and operates all year round day and night. Popular in countries with volcanic setting and likely to **increase** as technology spreads to LIC's. Currently does not contribute a large amount to the global energy mix.

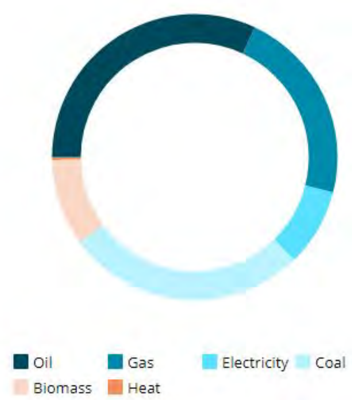
Global energy consumption varies, but is generally **higher in northern hemisphere countries**, which are more developed.



Global energy demands and trends by type of energy production methods are shown in the graphs. You can explore more using these links:

[Global Energy Facts](#) [Global Energy Use](#)
[Energy Systems Map](#) [Carbon Impact Map](#)





Energy Players

There are **key players** who have important roles in **securing energy pathways** and controlling prices.

- They explore, **exploit** and distribute energy resources.
- They own supply lines and **invest** in the distribution and processing of raw materials.
- They **respond** to market condition to increase the profits.

Most **energy players** are TNCs although there are exceptions such as Russia's state run Gazprom. Some names of key energy players include:

Saudi Aramco, Russian Gazprom, BP (UK), Shell (UK-Netherlands), ExxonMobil (USA), Petrobas (Brazil), Gazprom (Russia), PetroChina (China).

TNCs are the most prominent energy players for a variety of reasons:

- Some TNCs have more **economic value** than a small country, enabling the company to take action and invest in **large-scale projects** that a country may not afford.
- TNCs can **bypass political tensions** and access sources otherwise restricted to other countries. In certain parts of the world, an MEDC trying to help to exploit an energy source in an LEDC could be seen as a **direct threat** to the LEDC.
- TNCs may be inclined to **invest in local infrastructure**, logistics and development of workers' villages. This benefits all; the TNC benefits from faster transport links and a happier workforce, whilst the government receives 'free' investment.

Ofcourse, TNCs aren't always beneficial; TNCs may encourage **environmental degradation**, exploiting workers, **unsustainable** transportation (e.g. tankers liable to oil spills).

OPEC

OPEC is an IGO that with member countries which **export oil and petroleum**. OPEC producers control **81%** of the world's discovered oil reserves. Their mission is to unify the petroleum policies of its members to ensure the **stabilisation of oil markets.** They also want to create:

- an efficient and **regular supply** of oil to consumers.
- a **steady income** for producers.
- a fair return for those investing in the industry.

In the past, OPEC set quotas depending on the condition of the world economy. Supplies were boosted when demand rose whilst supplies were cut if demand fell.

Between 2012-2016, oil output was kept high to compete against the USA which produced vast amounts of oil through **fracking**. The flooding market caused a **collapse in global oil prices**. OPEC has also been accused of holding back production in order to increase prices and in turn increase profits for oil exporting nations. This can be detrimental to developing countries, who need vast, cheap amounts of oil to continue **economic development** and manufacturing.

National Governments

Governments try to **secure energy supplies** for their country and they also **regulate** the role of private companies. EU governments are trying to **reduce CO_2 emissions** and reduce **dependency** on fossil fuels.

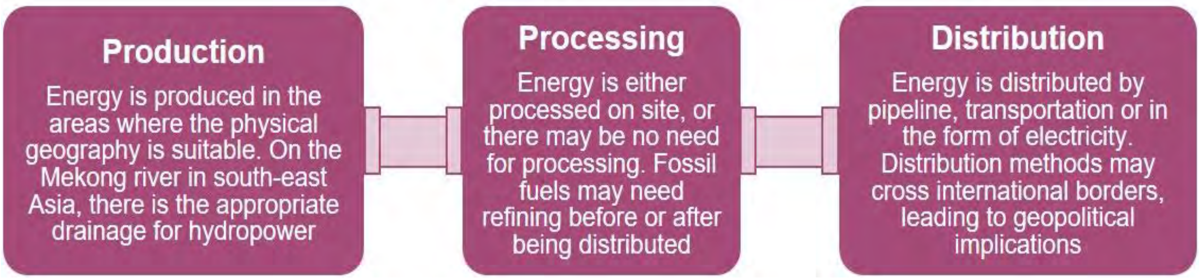
Consumers

Consumers create **demand** with purchasing choices usually based on price. As a country becomes richer and more educated, the population can **change their shopping habits** to reflect their needs: locally sourced, environmental friendly, reliable energy supply during winter and extreme weather.

For example, lots of energy companies now have **tariffs** on **imported or non-renewable sources** to reduce energy insecurities or **carbon-offset** their energy. Here, money raised on non-renewable energy can fund environmental work such as afforestation, research into carbon capture and storage, etc.. If consumers change their spending habits and only use these tariffs then companies will be encouraged to move towards more **green energy**. Consumers can have an impact on TNCs.

The Effect of Human Geography on Energy Supply

Most countries are **interdependent** for energy sources - they import energy from other countries. This has **geopolitical implications** and **requires the cooperation** of other countries:



Any stage in the energy supply chain may be used by countries as a **political tool**, to **cause or resolve tension** between countries. Different countries have varying '**national interests**'.

Example: Country (🌇) may want to **import gas** from country (🌅) to shift their **energy mix** away from coal at a **low cost**. This may require a **pipeline** passing through country (🌄) who do not want their **natural landscape** to be **spoilt by a pipeline**. Additionally 🌅 want the best price possible for their **natural gas**. This leads to **complicated geopolitical negotiations**.

TNC's may help if they have good links with 🌄 who they can **compensate** for building a pipeline through their landscape. Alternatively, **TNC's** may be **forced by powerful governments** in 🌇 to spend additional money on protecting the natural landscape in 🌄, even if that would make no **economic sense** to the TNC. However, it would provide a **natural gas pipeline** and **improve political relationships** between 🌇 + 🌅. Energy supply can be a very confusing process, influenced by **physical and human geography, TNCs, geopolitics, community groups and activists**! You will need a **case study** that concerns energy supply and these factors.

Problems with Achieving Energy Security

Fossil Fuel Supply

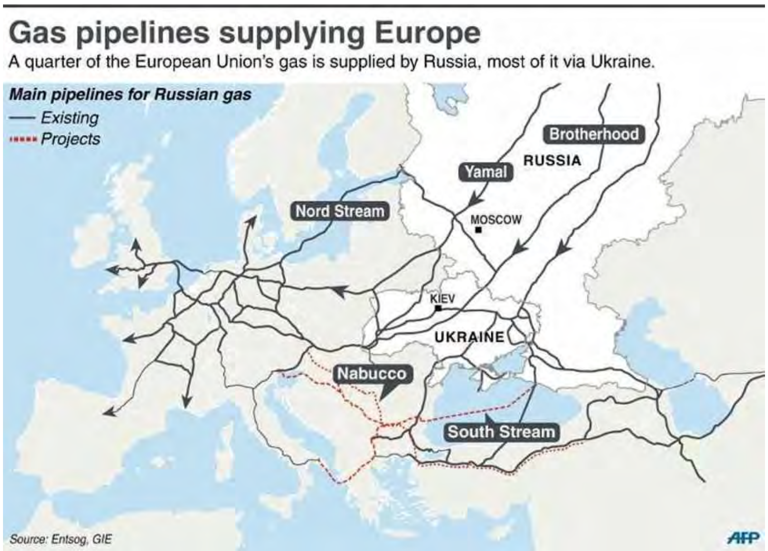
There is a **mismatch** between the **supply and demand** for fossil fuels. This is largely due to **inequality in wealth** and development, **natural resource** supplies and industrialisation.

Consumption of coal is declining worldwide, more than other fossil fuels. Over half of the world's oil come from OPEC and North American nations. However, since Europe has the largest demand for oil but produces very little, oil must be **transported and traded**. This may cause further **insecurity** and tensions.

Energy Pathways

There are many ways of transporting energy between countries. Here are some **energy pathways**, and their weaknesses.

- **Pipelines** are **efficient** in carrying billions of m^3 of oil across the world between countries. Many of these pathways depend on **international agreements**, so influence global politics.
- Around half of the world's oil is transported using **oil tanker** though **choke points** (a key point in the logistics of energy, which can easily be disrupted). If choke points



become blocked or threatened, then oil **prices can rise** very quickly and political tensions escalate. In the map above, Ukraine is considered a choke point in the EU's supply of oil - most pipelines from Russia run through Ukraine, and with increasing uncertainty in Ukraine relations with Russia, the EU's supply could become increasingly insecure.

Political Conflict

Conflicts and political altercations can severely limit energy security. For example, military conflict can destroy **infrastructure** which will restrict the flow of energy from source to use.

Disagreements between nations can also limit energy security. This is the case for Russia, who have several **political sanctions** against them. As Russia is a major supplier to Europe, this has caused some **shortages** in electricity.

Alternative Energy Sources

Within the last decade, new and unconventional energy sources have become more realistic. Some alternative sources aim to **increase supply** of fossil fuels, keeping energy prices low and improving energy security. However, some new alternative sources aim to **reduce CO_2** and greenhouse gas emissions whilst still meeting demand.

Unconventional Fossil Fuels

Shale Gas - Extracted through fracking, Shale Gas has received major environmental opposition. However, it provides 25% of the US's energy needs in 2015. **Fracking** is relatively new process of extracting Shale gas. Water, chemicals and sand are pumped into the ground to break up the shale, access the hydrocarbons and force them to the surface. **Horizontal drilling** helps to remove the gas reserves. There are **benefits and costs** of fracking:

Advantages:

- Less polluting than coal or oil
- Requires large amounts of water
- Could provide boost to the economy
- In the UK, the Royal Academy of Engineers believe we can make fracking safe

Disadvantages:

- Wastewater needs treating due to chemical contents
- May pollute groundwater aquifers. In the USA the water has become flammable due to pollution by fracking
- Earthquakes of low magnitude may occur, though they are not usually strong enough to pose a risk to humans. They may damage fracking infrastructure, causing further leakages
- The IPCC suggest it would be irresponsible to use shale gas

Deep-Water Oil - As oil supplies decrease, energy companies have begun extracting oil from deeper depths. Deep-water oil faces larger risks during extraction, and (similar to normal oil production) oil spills during transportation.

Advantages:

- Many engines and appliances are designed to operate on oil, therefore to continue to extract oil would avoid large changes to many important engines: vehicles, planes, etc.
- Shale gas produces half the emissions of coal, which would reduce global emissions without completely eradicating fossil fuel use.
- A large influx of readily available shale gas would drop the price of electricity.

- The majority of shale gas is found in the US, which would improve the US's economy and provide an alternative source to Russian oil (if political tensions between UK and Russia continue, our energy security is at risk).

Disadvantages:

- Fracking faces large environmental opposition, especially as fracking can trigger minor tremors.
- Shale gas is still more expensive to produce than conventional gas.

Tar Sands - The extraction of petroleum from sands involves high energies and boiling water, which can leave ponds of concentrated chemicals. Tar sands have a large environmental cost, but can be lucrative in profit and employment opportunities.

Advantages:

- Tar sand production creates economic growth and a large influx of jobs for rural regions.
- Fastest growing industry, producing the high-value bitumen for international exportation.

Disadvantages:

- The process of extracting bitumen is water and energy intensive, producing a large volume of waste (12 barrels or hot water produce 1 barrel of bitumen and 3 barrels of tailing pond waste).
- The liquid waste is left in tailing ponds, so water can be recycled after it seperates from the clay and salts. However, tailing ponds may also contain sulfate, chloride and ammonia which may infiltrate the groundwater stores and other water sources.
- Open mining involves removing the top layer of vegetation and soils to access the bitumen-sands, destroying habitats.

Alternatives to Fossil Fuels

As reserves of oil and gas begin to diminish, new reserves and technologies are being developed to **support further resource exploitation**. Currently new reserves are being discovered at a **lower rate than they are being exploited**. Environmental groups suggest that fossil fuel exploration should stop immediately and renewable energy used instead. In countries like Bahrain which are 75% reliant on oil for their GDP, this is not an economically viable or sustainable solution.

Renewable Energy:

Renewable energy is likely to be an important component of the future energy mix as it has a low carbon footprint (in most cases), the technology is always improving and becoming more efficient. Each renewable resource has **advantages and disadvantages**, though as time progresses the **disadvantages will decrease** as the technologies are improved. All have the disadvantage of being **visually unappealing** and causing **minor disturbances to the local environment.**

Examples of **new developments** in renewable technologies to research further are listed below:

- **Solar**: Concentrated Solar Power, Solar Powered Roads, Solar Power Roof Tiles
- **Wind Power**: Vortex Bladeless, Larger Blades, Offshore
- **Wave Power**: Eco Wave Power, Pelamis Wave Power
- **Tidal Power**: Swansea Bay (Defunct), Tidal Stream, MeyGen Tidal Stream Project
- **Geothermal**: FORGE, Enhanced Geothermal Systems (EGS)

However, not all countries have renewable energy sources due to their **physical geography** (lack of rivers, wind, sun, etc).

Solar Power

Source: Green Energy Times

Description: Panels that convert the sun's energy into electricity

- 👍 Costs are decreasing rapidly
- 👍 Large potential in desert areas
- 👎 Not very efficient yet (15-20%)
- 👎 Effectiveness dependent on climate and time of the year and day

Wind Power

Source: The Balance

Description: Wind drives large turbines and generators that produce electricity

- 👍 Low running costs
- 👍 Can be used year round
- 👍 Plenty of suitable sites
- 👎 Bird life can be affected
- 👎 Weather dependent

Wave Power

Source: E360 Yale University

Description: Waves force a turbine to rotate and produce energy - or other similar method

- 👍 Produce most electricity during winter when demand is highest
- 👍 Pioneer projects are commencing across the globe
- 👎 Very expensive and a 'perfect' solution is yet to be created
- 👎 Needs to survive storms

Tidal Power

Source: Renewable Energy World

Description: Incoming tides drive turbines in similar way to hydropower

- 👍 Has significant potential
- 👍 Reliable source of energy once installed
- 👎 Very expensive
- 👎 Few schemes currently operating in the world
- 👎 Impact on marine life

Geothermal

Source: Daniel Allen

Description: Water is pumped beneath the ground to hot areas and the steam from the water drives turbines to produce electricity

- 👍 Low maintenance costs
- 👍 Suitable where other technologies might not be

- High installation cost
- Risk during earthquakes etc.

Many people claim that renewable energy can completely replace non-renewables but this is unlikely because:

- Not all renewable energy sources provide the same amount of energy; you need more wind turbines than hydroelectric dams.
- Oil prices in 2015 dropped significantly and as renewables are generally more **expensive**, they became less attractive.
- Some forms of renewable energy have **negative impacts** e.g. HEP could lead to large swathes of land getting flooded.

Nuclear Power:

Nuclear energy is considered to be a **recyclable energy**, since little Uranium is needed to produce large amounts of energy through fission. Despite being the most realistic option for replacing fossil fuels, there are some **risks** to nuclear energy:

- **Nuclear Disasters** like Chernobyl and Fukushima (mainly due to mismanagement) could happen again
- The risk that nuclear powered stations may be infiltrated during **conflict** or by **terrorists**.
- **Radioactive waste** has to be disposed of safely, often through vitrification in underground caverns.
- The technology involved is only accessible for developed countries. Operational costs are quite low but construction and **decommissioning costs** are extremely high.
- **Energy security** may be compromised if countries own and fund nuclear plants in other countries (e.g. UK nuclear plants are owned by French and Chinese TNCs)

Nuclear Power

Advantages	Disadvantages
Very low carbon footprint	Large-scale disasters do occur
High efficiency	Produces radioactive waste which is difficult to dispose of
Safety always improving	Very high cost
May have fewer negative impacts than fossil fuels	Lack of support from general public
Technology becoming more affordable and accessible for NIC's	

Biofuels:

Biofuels, in theory, are a good alternative to fossil fuels. The process of burning biofuels is **carbon neutral** - CO_2 taken in by a plant during photosynthesis will then be released during combustion.

However, across the globe, forests have been **cleared** to plant oil palms (Malaysia), oilseed rape (EU) and maize (USA) to manufacture biofuels. There are many **environmental**

implications with deforestation for biofuels - loss of **biodiversity** and habitats, reduced vegetation to intake CO_2.

In addition, clearing land to grow biofuels will create **food insecurity**. Many Swiss, Swedish and American companies have bought land in order to grow biofuel crops but this has **inflated land prices**. A shortage of food in 2001 in Mexico lead to the **Tortilla Riots**; corn was bought by TNCs to produce biofuels for cars, which increased the price of corn making it **unaffordable** for Mexican families to buy to eat.

<table>
<tr><th colspan="2">SWOT Analysis for Biofuels</th></tr>
<tr><td>Strengths
- Renewable energy source.
- Lower emissions (carbon neutral) than fossil fuels.
- Can be grown very easily.</td><td>Weaknesses
- Takes land that food can be grown on.
- Requires fertilizers and pesticides.
- Requires large volumes of water
- Loss of carbon sinks as forest destroyed to make way for plantations.</td></tr>
<tr><td>Opportunities
- Provides rural inward investment and local development projects.
- Positive multiplier effect.
- Fuel earns export income.</td><td>Threats
- Biofuel production will reduce food production, leading to future insecurity.
- Water sources may become contaminated with chemicals.
- Where a biofuel source is also a food supply, food prices can increase when shortages occur.</td></tr>
</table>

Reducing Carbon Emissions

There are several strategies to try to take some CO_2 out of the atmosphere or reduce emissions. However, these tend to be **expensive** and must be carried out on a **national scale** to take effect.

Carbon Capture and Storage (CCS) is a technological strategy used to capture CO_2 emissions from coal fired power stations. The gas collected from the power plant, **compressed and stored** into underground aquifers or disused mines. CCS could help to reduce carbon emissions by **19%** but due to their cost, only 1 scheme exists currently.

Hydrogen fuel cells provides an alternative to the use of oil. Hydrogen is the most abundant element in the atmosphere but it usually combines with other elements especially carbon. Therefore Hydrogen needs to be separated and stored before use. Fuel cells convert chemical energy found in hydrogen into electricity and this produces pure water as a by-product. These fuel cells are much more efficient than petrol engines in vehicles.

Threats to the Water and Carbon Cycle

Across the globe, there are contrasting threats and demands to the land, water supply and Carbon fluxes.

This section links the Water Cycle notes and Carbon Cycle notes - make sure you read both detailed notes!

Deforestation

Forests cover around **30%** of the Earth's land area. Forests **intercept rainfall** and increase **groundwater storage**. A loss of even a small number of trees can **disrupt weather** patterns which could lead to more intense **flooding and droughts**.

More than half of forested land is cleared due to increased demand for **commodity production**: soy, palm oil, beef and paper production. Land is also being converted to build **dams** and **reservoirs**, therefore land clearing may increase as energy demands increase or water supplies decrease.

By 2015, 30% of all global forests had been cleared. Annually, around 13 million hectares are lost every minute.

Impacts on Water Cycle

- Less **interception** so more surface runoff and shorter lag time.
- Shorter **lag time** will increase flooding risk.
- More **soil erosion** as there are no tree roots to bind soil together.
- Eroded material in rivers.
- Less evaporation from **vegetation**.

Impacts on Carbon Cycle

- Reduction in carbon stored in **biosphere**.
- Reduction in carbon absorbed for **photosynthesis**.
- More carbon released from **combustion**.

Regional Trends

- 90% of forests in the UK and USA were lost through deforestation by the 19th century.
- Boreal forests have been threatened in Russia and Canada for oil and tar sands production.
- In Africa and South America, most forests have halved in area since the 1960s
- In Indonesia, large areas of forest land have been cut down or burnt to make way for palm oil plantations for which demand is increasing significantly.

Implications for Human Wellbeing

Over 1.6 billion people **depend** on forests and more than 90% of these people are amongst the **poorest in society**. Between 2000 and 2010, deforestation affected 13 million hectares of forest every year.

Many people join **pressure groups** like Greenpeace and the WWF to oppose forest loss. Greenpeace found that **TNCs** don't do enough to prevent deforestation, forest fires and human rights abuses.

Grassland Conversion

There are two main types of grassland:

- **Temperate grasslands** which have no trees
- **Tropical grasslands** or Savannahs which have trees but infertile soil

Role of grasslands:

- **Traps moisture** and floodwater
- Absorb **toxins** from soil
- Provide cover for dry soils
- Provides **habitats** for wildlife
- Act as a carbon sink

Impacts on Carbon Cycle:

Converting grasslands into agricultural farms will

- Release CO_2 into atmosphere initially.
- There is a **net increase** in CO_2 emissions as biofuel crops need fertilisers.
- Cultivated soil is more susceptible to erosion.

Ocean Health

Oceans absorb around **30%** of the atmosphere's CO_2. Since 1800, around 50% of all carbon emissions came from the **combustion** of fossil fuels. As CO_2 in the ocean increases, the pH of the ocean decreases **(increasing acidity)**.

Overfishing is also creating imbalance in ocean health, threatening ocean security in the future.

- Fishing supports **500 million people** of which 90% live in LDCs.
- Fish is a **cultural choice** for wealthy MEDCs where as it is a necessity for people in LEDCs.
- Millions of small-scale fishing families depend on seafood for their **income** as well as for food.

In addition to fishing, many countries rely on their marine life to attract **tourism**. Therefore overfishing and acidification (affecting coral reefs) can have direct consequences for a country's economy and employment.

Impacts for wildlife:

As oceans become more acidic, **corals** cannot absorb alkaline **CaCO3** in order to maintain their skeletons, in turn reefs begin to **dissolve**.
Algae provide food to corals through **photosynthesis**. If the water becomes warm enough, the algae leave the coral, leaving the coral to turn white **(Coral bleaching).**

Coral reefs

- Shelter 25% of marine species
- Protect shorelines
- Support fishing industries
- Provide income through tourism

Climate Change

Increased carbon emissions are enhancing the greenhouse effect significantly and this is affecting the world's climate.

Impacts on Water Cycle & Climate:

- More frequent and more intense **storms** and hurricanes.
- **Rising sea levels**, therefore more coastal erosion and some land lost (isostatic sea level rise).
- More frequent **floods, droughts** and heatwaves.

Changes in ocean currents and atmospheric circulation could have an impact on patterns of **precipitation, evapotranspiration** and temperature.

Scientists have use climate model simulations to investigate shifts in climate zones. They believe that for and increase of 2 degrees, 5% of the Earth's land area shifts to a different climate zone.

In 2015, there were some unusual weather patterns:

- Droughts in parts of Africa, Pakistan and India
- Flooding in the USA and Europe
- Warm temperatures in Russia and Siberia

Impacts on the Carbon Cycle

Due to Climate Change, global average temperatures are predicted to rise **(global warming)** which will lead to:

- More CO_2 being released from **boreal forests** as they become drier and forest fires start.
- CH_4 from **thawing permafrost**.
- CH_4 from the **destabilization of wetlands**.

Loss of **Arctic Albedo** (white snow reflects solar radiation, earth and dark surfaces will absorb solar radiation) may lead to increased **permafrost thawing**. If some arctic bogs thaw, huge quantities of **methane and CO_2** gas will be released into the atmosphere, leading to **irreversible** changes to climate.

Climate Change

Greenhouse gases are likely to increase in the future as more countries **industrialise** and develop. Greenhouse gases remain in the atmosphere for a long time and so even if global emissions were reduced, surface air temperatures would still **continue to increase**.

It is very **difficult to predict** future emission levels and so scientists use various scenarios to show projected greenhouse gas concentrations. There are several **uncertainties** in estimating future Climate Change, but they have identified several **tipping points and feedback mechanisms** that scientists believe would accelerate change.

Uncertainty over Climate Change

- **Oceans and forests** are carbon stores.
- Oceans take a very **long time to respo**nd to changes in greenhouse gas concentrations.
- Weather will have a direct influence over **vegetation productivity** and the rate of chemical reactions. As how climates will change is unknown, future vegetation changes is also unknown.

Alternatively, human factors will create the most uncertainty in predictions:

- **Economic growth** – There is a correlation between economic growth and energy consumption. After the financial crisis in 2007, there was concern that CO_2 emissions would begin to rise as GDP growth picked up.
- **Population change** – Increasing affluence in emerging economies means that that by 2050 there could an additional 1 billion consumers which could lead to more emissions due to more energy consumption.
- **Technology & Globalisation** - Increased globalisation leads to more traveling and transportation of goods which could mean more emissions. However, technological advancements may compensate and decrease emissions created by the inteconnected world.

Feedback Mechanisms

Negative feedback dampens the original process whilst **positive feedback** amplifies the original process. Both examples are of positive feedback loops, which will **accelerate** Climate Change:

<u>Peatlands</u>
Peat is the **accumulation** of partly decayed vegetation, which stores a large amount of carbon. Warming causes peat to dry out and the rate of **decomposition increases**. An increase of 4 degrees causes a 40% loss of soil organic carbon from shallow peat and 86% from deep peat. Peatlands emit carbon in the form of **methane** which increases greenhouse gases and accelerates enhanced Greenhouse Effects.

Permafrost

When permafrost melts, trapped carbon is released into the atmosphere as CO_2 and methane which increases greenhouse gas concentrations in the atmosphere. This leads to higher temperatures and further melting of ice.

Tipping Points

A climate tipping point is a **critical threshold**; when this threshold is reached, small changes in the global climate system can transform a stable system irreversibly.

Forest Die-back

Rainfall in the Amazon is largely **recycled**. If there is a drought in the rainforest, trees may die. A tipping point could be reached when moisture can no longer be recycled (due to too few trees to intake moisture) which leads to more trees dying.

In the **boreal forest ecosystem**, hot and dry summers lead to water stress which can result in a loss of trees. A tipping point could be reached when trees no longer absorb much CO_2 which in turn increases the concentration of greenhouse gases in the atmosphere, leading to further dry summers.

Thermohaline Circulation

Cold water in the North Atlantic forms part of the **thermohaline circulation**. To keep warm water heading from the tropics towards Britain, heavy water must sink in the North. The melting of Northern ice sheets releases large amounts of **fresh water** into the ocean which is less dense and has low salinity. This will **disrupt the circulation** of water, affecting the temperature of the ocean reaching the ocean and in turn the weather of the UK. It is believed by some scientists that the thermohaline circulation is slowing down. If it stops then the world will go into another ice age.