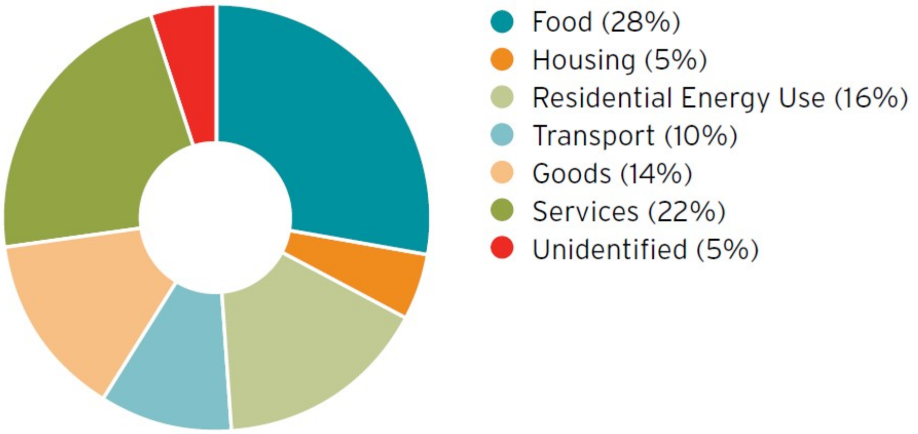
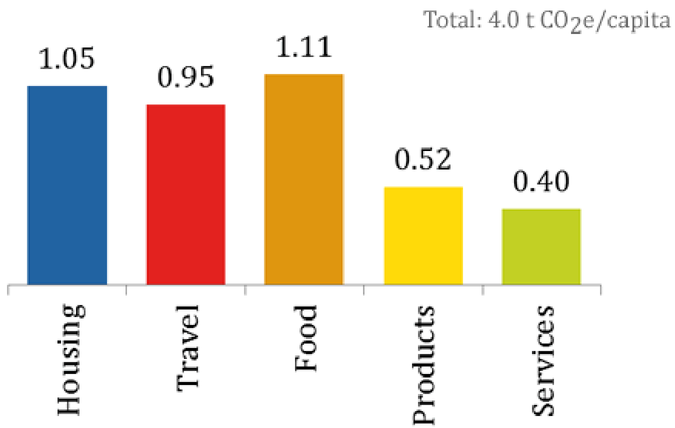
Footprint = ***impact***

- **Ecological footprint**
- Water footprint
- Carbon footprint

Victoria's Ecological Footprint by consumption category



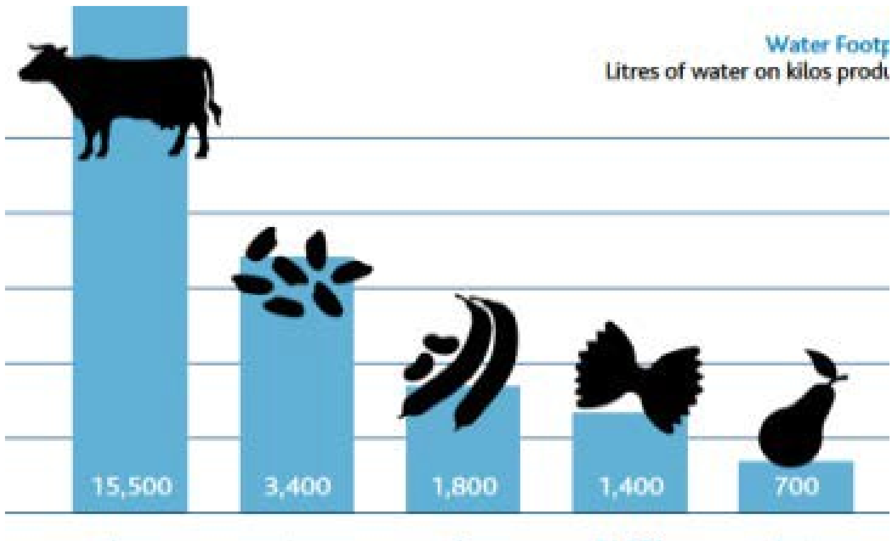
Average Personal Footprint: t CO_2e/cap (2001)



Note: Based on the average global footprint per capita in carbon dioxide equivalents. Figure excludes capital, government and land use change emissions. In 2010 the average personal footprint is estimated to be about 5.0 t CO_2e/capita.

Sources: Hertwich & Peters 2009, WRI

Shrink That Footprint



Ecological Footprint

- A key sustainability metric
- Governed by the ‘Global Footprint Network’
- “Measures human use of ecosystem products and services in terms of the amount of bioproductive land and sea area needed to supply these products or services.”
- Includes demand for material consumption and waste disposal.

Ecological Footprint

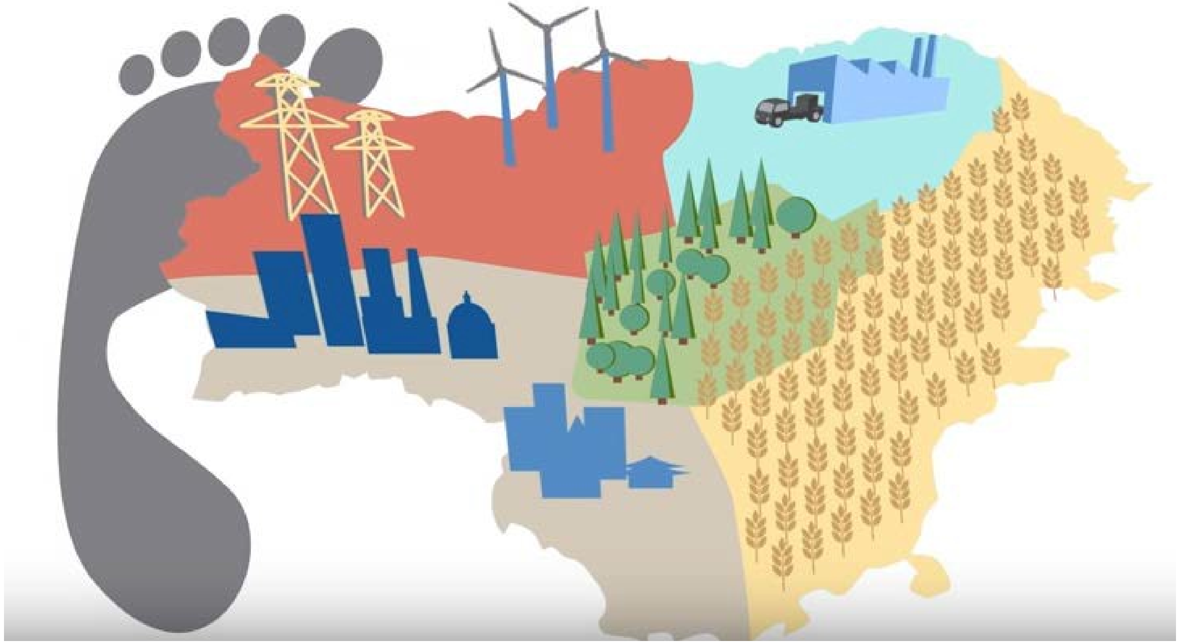
- Aims to provide scientifically robust and transparent calculations
- Allows for comparisons of countries' demands on global regenerative and absorptive capacity.

Top 10 countries with the biggest ecological footprint per person 2016

National Footprint Account

- https://youtu.be/_T5M3MiPfW4

http://data.footprintnetwork.org/#/sustainableDevelopment?cn=all&type=BCpc,EFCpc&yr=1994



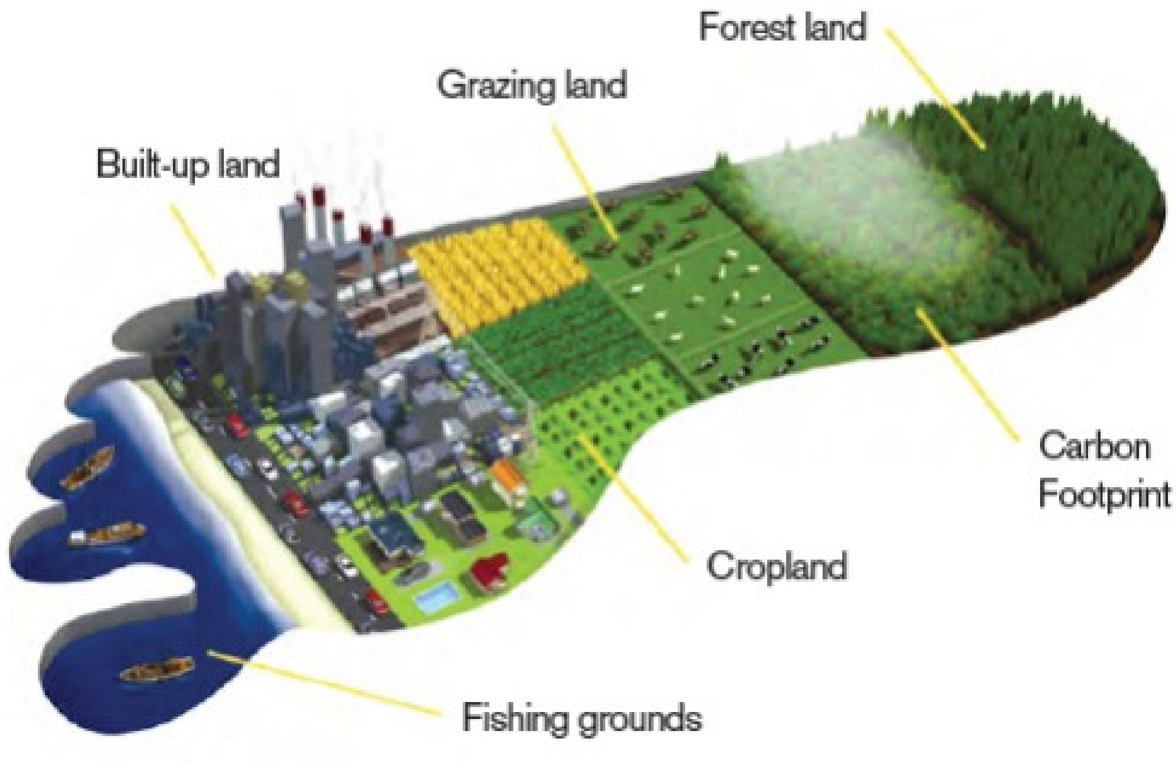
Ecological Footprint Calculation

- Every human activity uses biologically productive land and/or fishing grounds.
- The Ecological Footprint is the sum of these areas, regardless of where it is located on the planet.
- Units = Measured in global hectares (gha).

- Because trade is global, an individual or country's Footprint includes land or sea from all over the world.

Components of Ecological Footprint

- Covers six land use types:
- Each is a different biologically productive 'land type'



Land Use Type 1 – Crop Land

- Area for growing all crop products
  - Vegetables
  - Livestock feeds
  - Oil crops
  - Rubber

- The most bioproductive land use type

Land Use Type 2 – Grazing Land

- Also called 'permanent pasture'
- Area of grassland in addition to crop feeds to support livestock for
  - Meat;
  - Dairy;
  - Hide and;
  - Wool products

Land Use Type 3 – Fishing Grounds

- The amount of annual primary production required to sustain a harvested aquatic species
- Fishing grounds
- Marine space

Land Use Type 4 – Forest Land

- Forest products
  - Fuel wood
  - Timber
  - Paper products

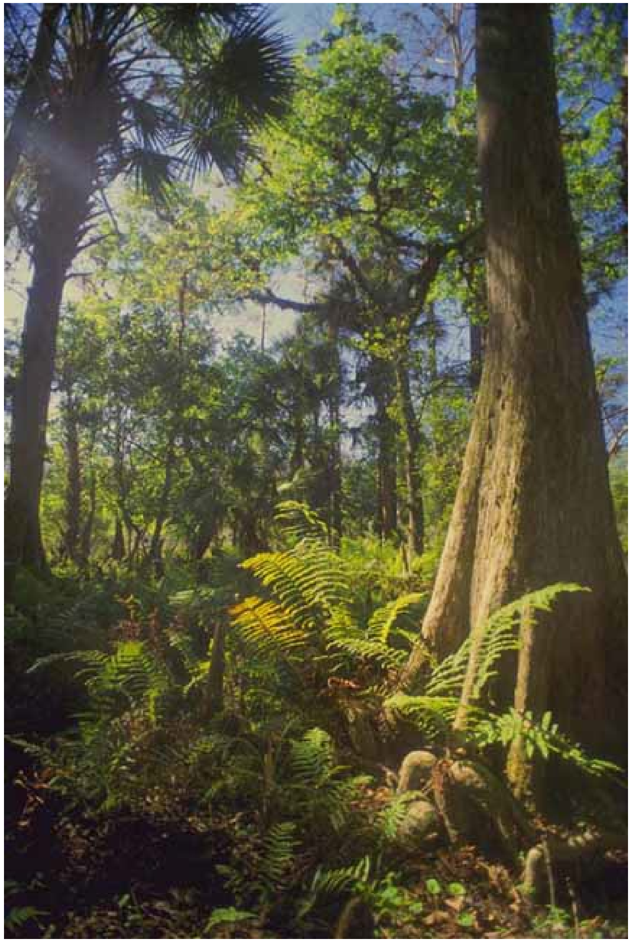
Land Use Type 5 – Built-up Land

- Built environment
- Area of land covered by human infrastructure
  - Transportation
  - Housing
  - Industrial structures
  - Reservoirs for hydroelectric power generation

Land Use Type 6 – Carbon Uptake Land

- Also called ‘Energy land’ or ‘Carbon footprint’

- The amount of forest land needed to uptake carbon emissions from fossil fuel combustion
- i.e. CO_2 sink
- Most carbon uptake occurs in forests
  - A subcategory of forest land
- Usually the largest contributor to total Ecological Footprint.



Carbon

Accounts for the area of forest land required to absorb CO_2 emissions from burning fossil fuels, land use change and international transport, that are not absorbed by the oceans.

Grazing land

Represents the area used to raise livestock for meat, dairy, hide and wool products

Forest

Represents the forest area required for the supply of timber, pulp and fuel wood

Fishing grounds

Calculated from the estimated primary production required to support fish and seafood catches including catches from aquaculture

Cropland

Represents the area used to grow crops for food and fibre for human consumption as well as the area for animal feed, oil crops and rubber

Built-up land

Represents the area of land covered by human infrastructure, including transportation, housing, industrial structures and reservoirs for hydropower

The measure of global hectares (gha):

Both the Ecological Footprint (which represents demand for resources) and biocapacity (which represents the availability of resources) are expressed in units called global hectares (gha). One gha represents the productive capacity of one hectare of land with world average productivity

Calculating Ecological Footprint

- In its most basic form:

$$Ecological\ Footprint[\mathrm{gha}] = \frac{D_{ANNUAL}}{Y_{ANNUAL}}$$

- Where:
  - D is the annual demand of a product [kg/y]
  - Y is the annual yield of the same product [kg/gha.y]

Units of Ecological Footprint

- Physical land demanded = hectares (ha)
  - 1ha = 10,000 m^2
- Footprint area = global hectares (gha)
  - Scale factors convert physical land demanded to world average biologically productive land

- Two scale factors:
  - *The yield factors* (that compare national average yield per hectare to world average yield in the same land category);
  - *The equivalence factors* (which capture the relative productivity among the various land and sea area types).

Yield Factors

- Account for countries' differing levels of productivity for particular land use types.
- In every year, each country's yield factor may change
- **In our tutorial we can assume yield factor = 1**

	Cropland	Forest	Grazing Land	Fishing Ground
World average yield	**1.0**	**1.0**	**1.0**	**1.0**
Algeria	0.6	0.9	0.7	0.9
Guatemala	0.9	0.8	2.9	1.1
Hungary	1.5	2.1	1.9	0.0
Japan	1.7	1.1	2.2	0.8
Jordan	1.1	0.2	0.4	0.7
New Zealand	2.0	0.8	2.5	1.0
Zambia	0.5	0.2	1.5	0.0

Table 1: Sample Yield Factors for Selected Countries, 2005.

Equivalence Factor (gha/ha)

- A productivity based scaling factor that converts a specific land type (such as cropland or forest) into a **universal unit of biologically productive area**, (i.e. global hectare).

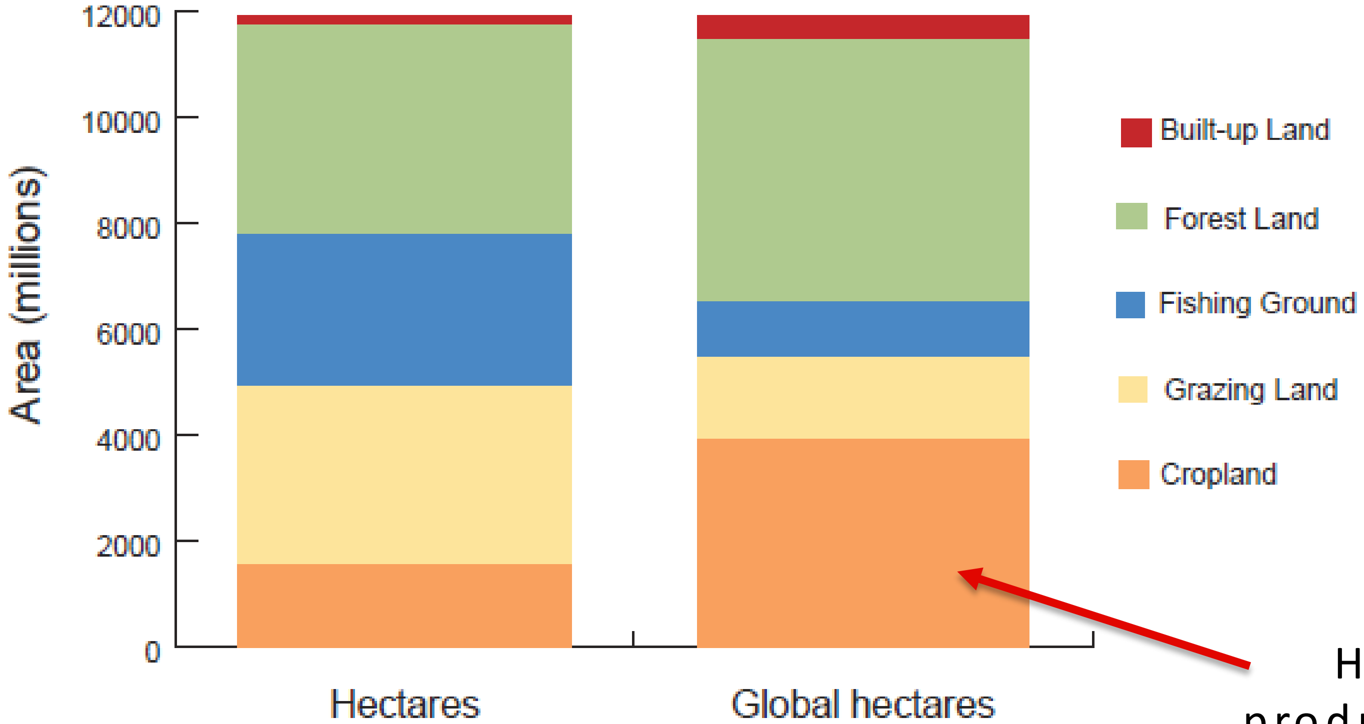
Table 1: Equivalence factors (From "Ecological footprint calculators: technical background paper" by EPA Victoria, 2005)

Component	Equivalence factor
Cropland	2.17
Forest	1.35
Permanent pasture	0.47
Built-up land	2.17
Energy land	1.84
Marine (fishing ground)	0.06

- **EQF > 1**when: Land types (e.g., cropland) have a productivity higher than the average productivity of all biologically productive land and water area on Earth.
- **EQF < 1**when: Land types (e.g., grazing lands) have a lower productivity.

Physical land demanded

Relative ecological footprint



High productivity = high gha

Figure 1. Relative Area of Land Use Types Worldwide in Global Hectares and Hectares, 2007

Source: Ecological Footprint atlas 2010

Ecological Footprint Calculation

$$EF = \frac{P}{Y_N} \cdot YF \cdot EQF \quad \text{(Eq. 1a)}$$

where P is the amount of a product harvested or waste emitted, Y_N is the national average yield for P, and YF and EQF are the yield factor and equivalence factor, respectively, for the land use type in question.

In our tutorial we can assume yield factor = 1

- **EQF are given (gha/ha)**
- **P and Y_n are given in the question or can be calculated**

Key Assumptions of EF Calculation

- Most consumed resources and generated wastes can be tracked.
- Most resource and waste flows can be measured. Those that cannot be measured are excluded - (underestimation).
- Must be expressed on an annual basis.
- Human demand, expressed as the Ecological Footprint, can be directly compared to nature's supply, biocapacity, when both are expressed in global hectares.
- Area demanded can exceed area supplied if demand on an ecosystem exceeds that ecosystems regenerative capacity. This situation, where Ecological Footprint exceeds available biocapacity, is known as overshoot.

Example

- Australia consumes 210,000 tonne of bananas per year (t/y)
- Average banana yield is 12 tonne per ha per year (t/ha/y)
- What is the ecological footprint of **growing** bananas in Australia?


Example

- What is the ecological footprint of growing bananas in Australia?
- Consumption = 210,000 (t/y)
- Yield = 12(t/ha.y)

Step 1:Calculate physical land area demanded

$$\frac{210{,}000\ [\mathrm{t/y}]}{12\ [\mathrm{t/ha.y}]} = 17{,}500\ ha$$

Example

- What is the ecological footprint of growing bananas in Australia?
- Consumption = 210,000 (t/y)
- Yield = 12(t/ha.y)

Step 1: Calculate physical land area required

$$\frac{210{,}000\ [\mathrm{t/y}]}{12\ [\mathrm{t/ha.y}]} = 17{,}500\ ha$$

Step 2: Find the relevant equivalence factor = 2.17 gha/ha

Table 1: Equivalence factors (From "Ecological footprint calculators: technical background paper" by EPA Victoria, 2005)

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Example

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Step 1: Calculate physical land area required

$$\frac{210{,}000\ [\mathrm{t/y}]}{12\ [\mathrm{t/ha.y}]} = 17{,}500\ ha$$

Step 2: Find the relevant equivalence factor = 2.17 gha/ha

Step 3: Convert to ecological footprint (i.e. gha)

$$17{,}500\ ha\ \times 2.17\ gha/ha = \mathbf{37{,}975\ gha}$$

Example

- What is the ecological footprint of **growing** bananas in Australia? = 37,975 gha
- This includes only cropland. What about processing, storage and transportation?

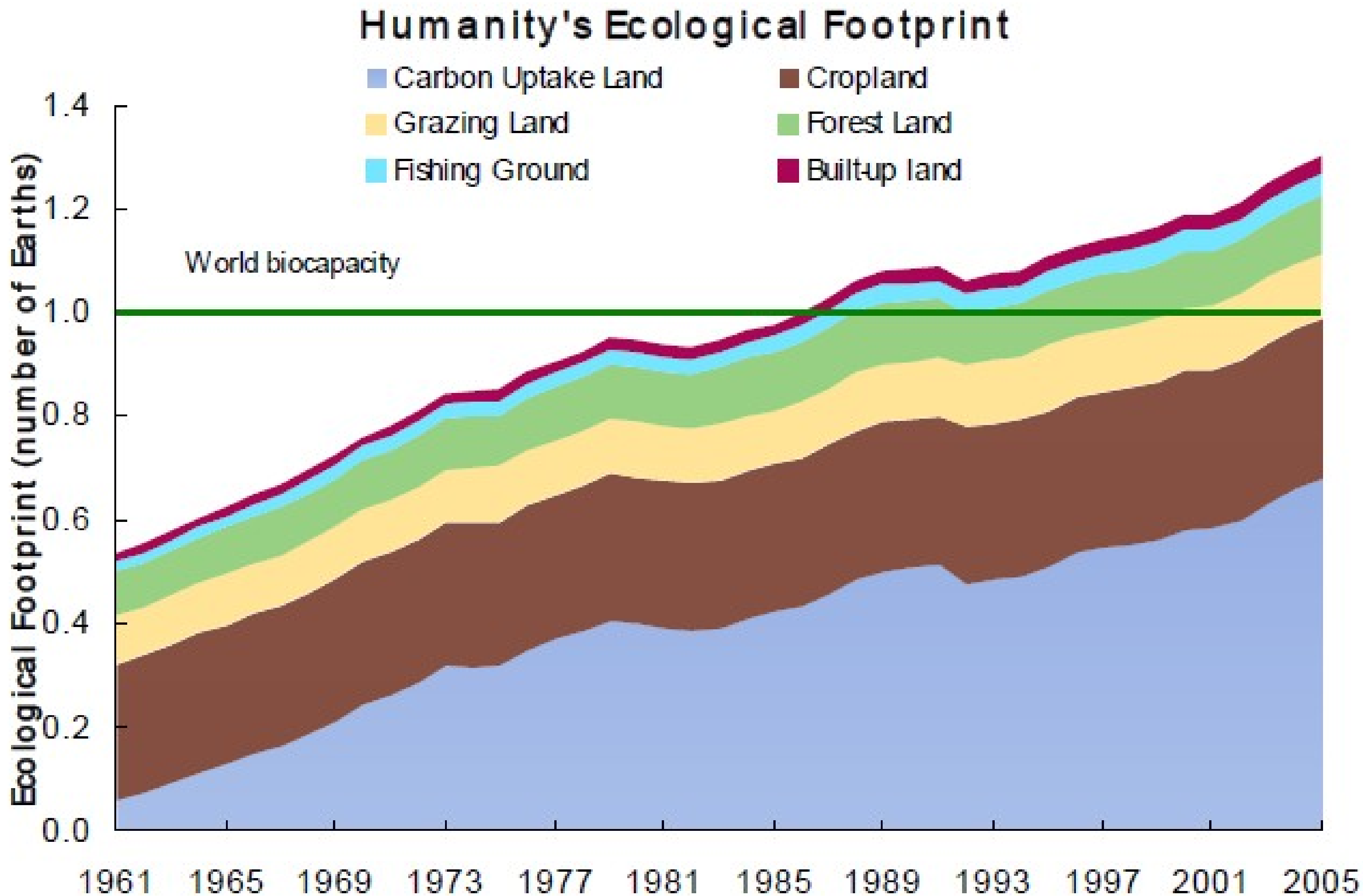
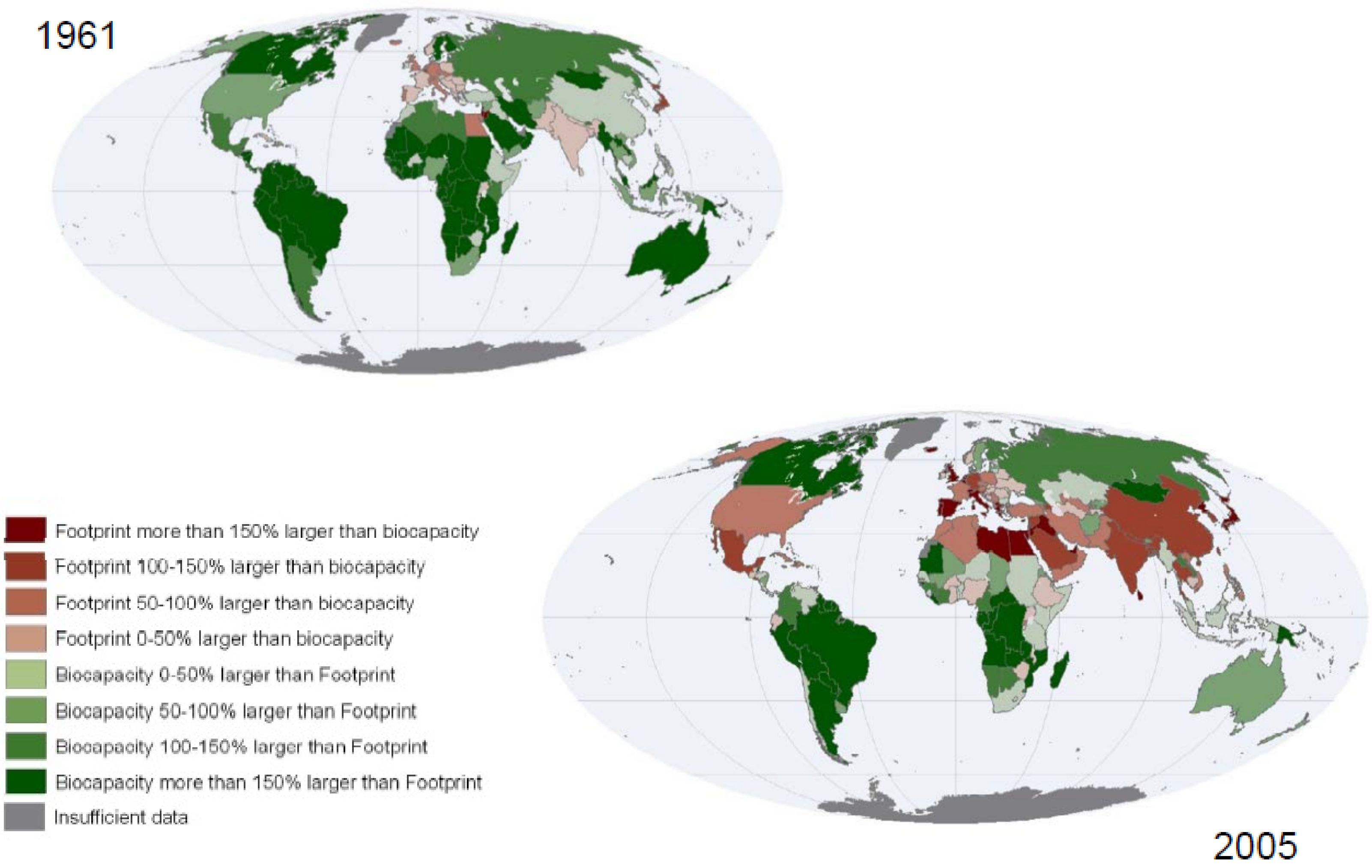



Figure 4: World overshoot according to the 2008 edition of the National Footprint Accounts. Humanity's Ecological Footprint, expressed in number of planets demanded, has increased significantly over the past 45 years.

Ecological Footprint



Transportation Footprints

Example

- If one person travels 5 kilometres twice each workday:
  - Bicycle: 122 sq meters
  - Buses: 301 sq meters
  - Cars: 1,442 sq meters

Agricultural Footprints

Example

- Open field production of tomatoes takes up more physical land than greenhouse production
- But greenhouse production has a much larger ecological footprint (10 – 20 times)
  - Energy
  - Water
  - Fertilizer
  - Other inputs

National Footprints

Example

- In U.S. each person uses about 4.5 hectares/person
- Worldwide average = 1.5 hectares/person
- Therefore if everybody were to adopt the U.S. consumptive style, we would need 3 planets

Ecological Footprint Analysis

Advantages

- Value as an educational tool
  - Demonstrate degrees of sustainability or unsustainability
- Easily understandable concept for a broad cross-section of people
  - Aggregates a number of environmental factors, such as land types and consumption levels, into a single environmental indicator

Ecological Footprint Analysis

Disadvantages

- *A significant over-simplification*
- Little information about the nature of the environment
  - Loss of biodiversity
  - Reduced quality of water etc.

- Not considered to be a suitable tool for environmental planning
  - **World-average** productivity used to calculate the footprint, meaning
  - Much of the detail is lost at a regional scale

Scientist's Objection to Footprint Analysis

- Footprint Analysis is a crude simplification
- Interactions with nature are complex
- Can we reduce such complexity to a matter of hectares?

Answer to Scientists Objections

- Footprint analysis may not tell the whole story
- Is good enough to show us what must be done
- Complex systems need to be simplified
- Footprints may actually underestimate impact of humans on the environment

Uncertain Future Objection to Footprint Analysis

- Prediction about the future are always way off
- Can be sure the future will be different from what we expect

Answer to Uncertain Future

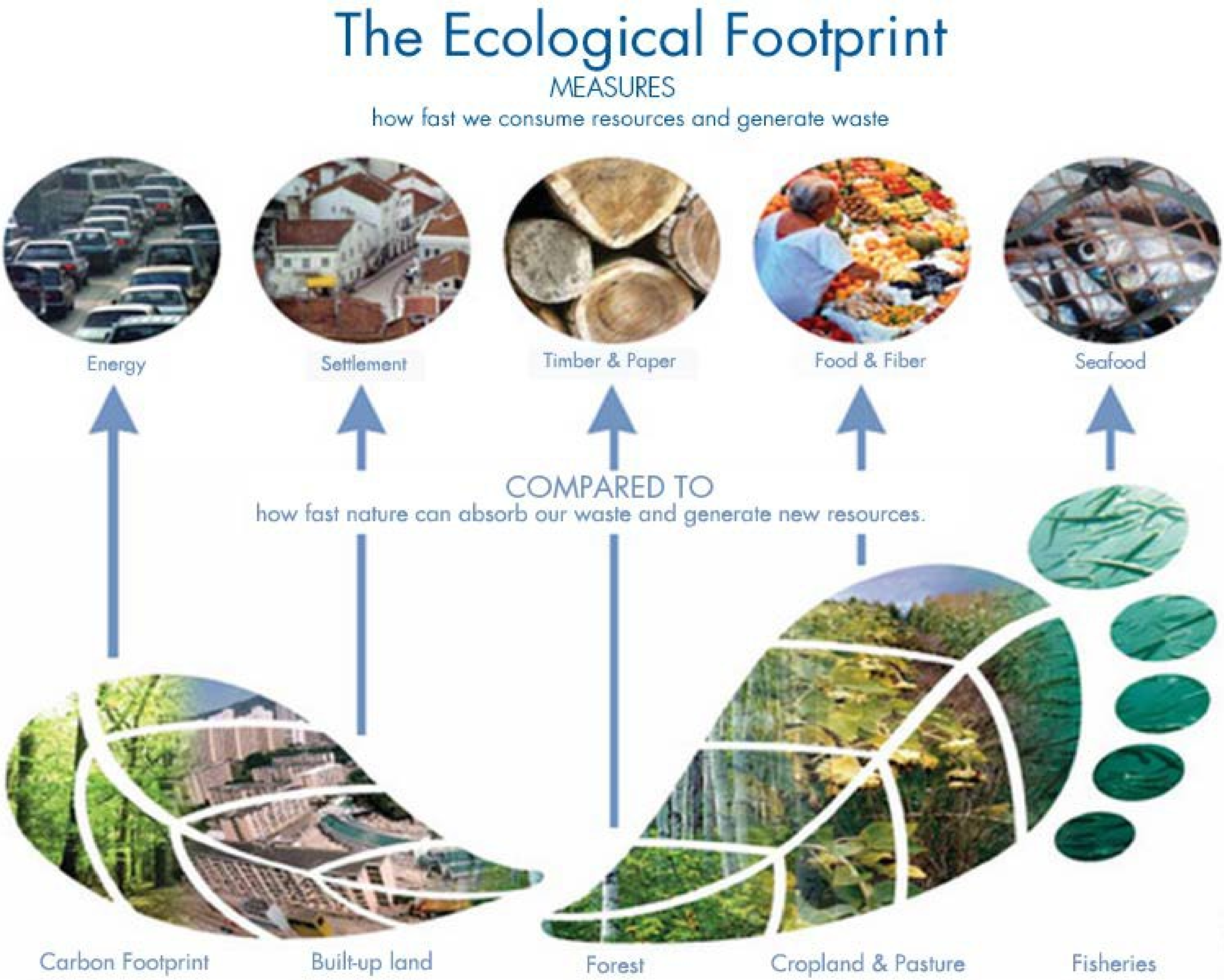
- Footprint Analysis is not a predictive tool
- Is an “ecological camera” that takes a snapshot of our current demands on nature
- Extrapolation into future really measures sustainability gap”
- Footprints also show material inequity
- Footprints show us how much we must
  – reduce our consumption
  – improve technology
  – change behavior to be sustainable

Optimism Objection to FA

- Footprints are depressing
- Apocalyptic visions never come true
- Look on the bright side!

ANSWER:

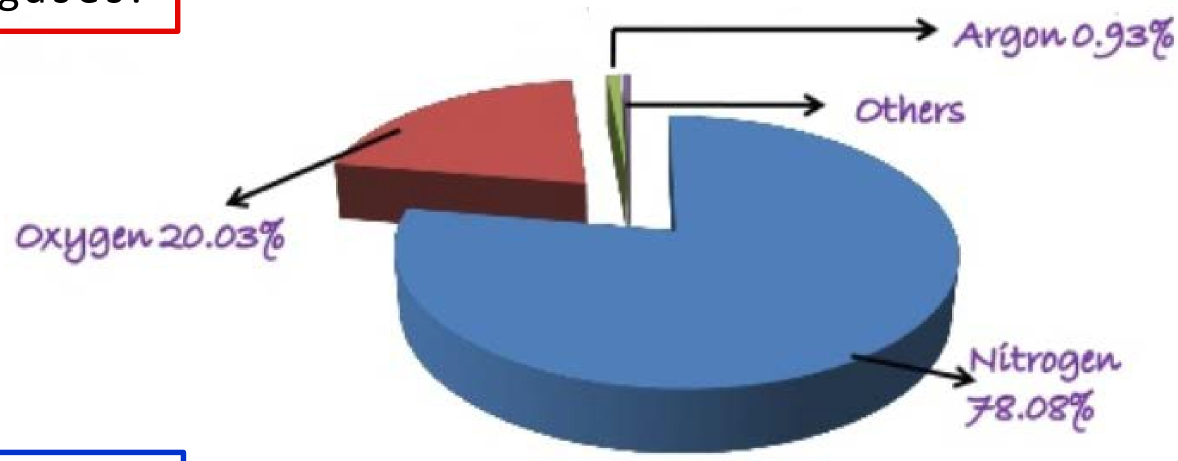
- Acknowledging finite capacity of Nature is not pessimistic: is realistic
- It allows wise decisions
- If we choose wisely, may increase quality of life
- The sooner we start moving toward sustainability, the easier it will be for humanity


The Ecological Footprint
MEASURES
how fast we consume resources and generate waste
Energy
Settlement
Timber & Paper
Food & Fiber
Seafood
COMPARED TO
how fast nature can absorb our waste and generate new resources.
Carbon Footprint
Built-up land
Forest
Cropland & Pasture
Fisheries

Emissions

Composition of the earth's atmosphere

Major gases:

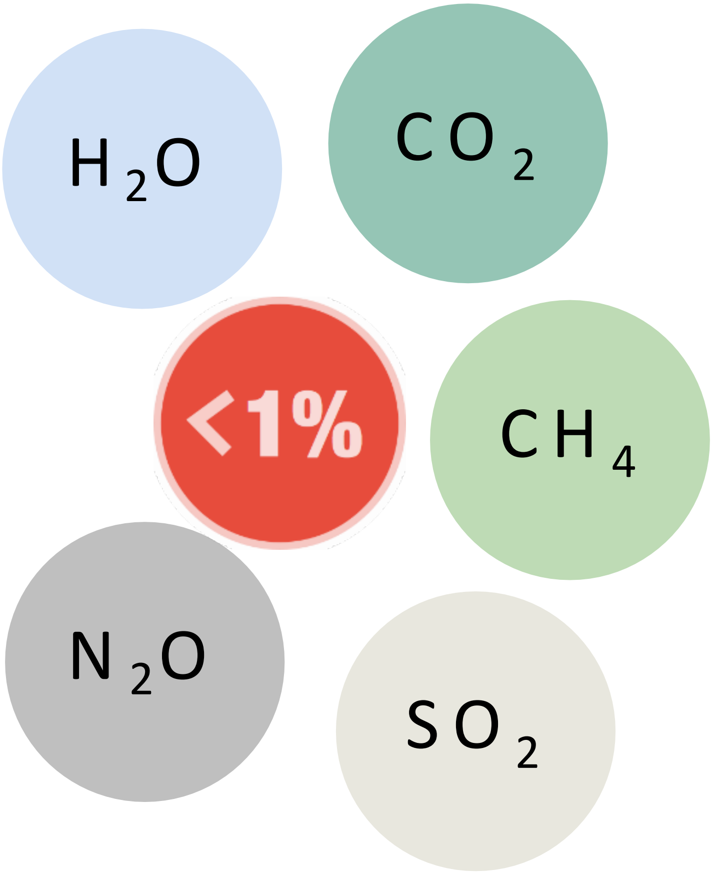


Trace gases:

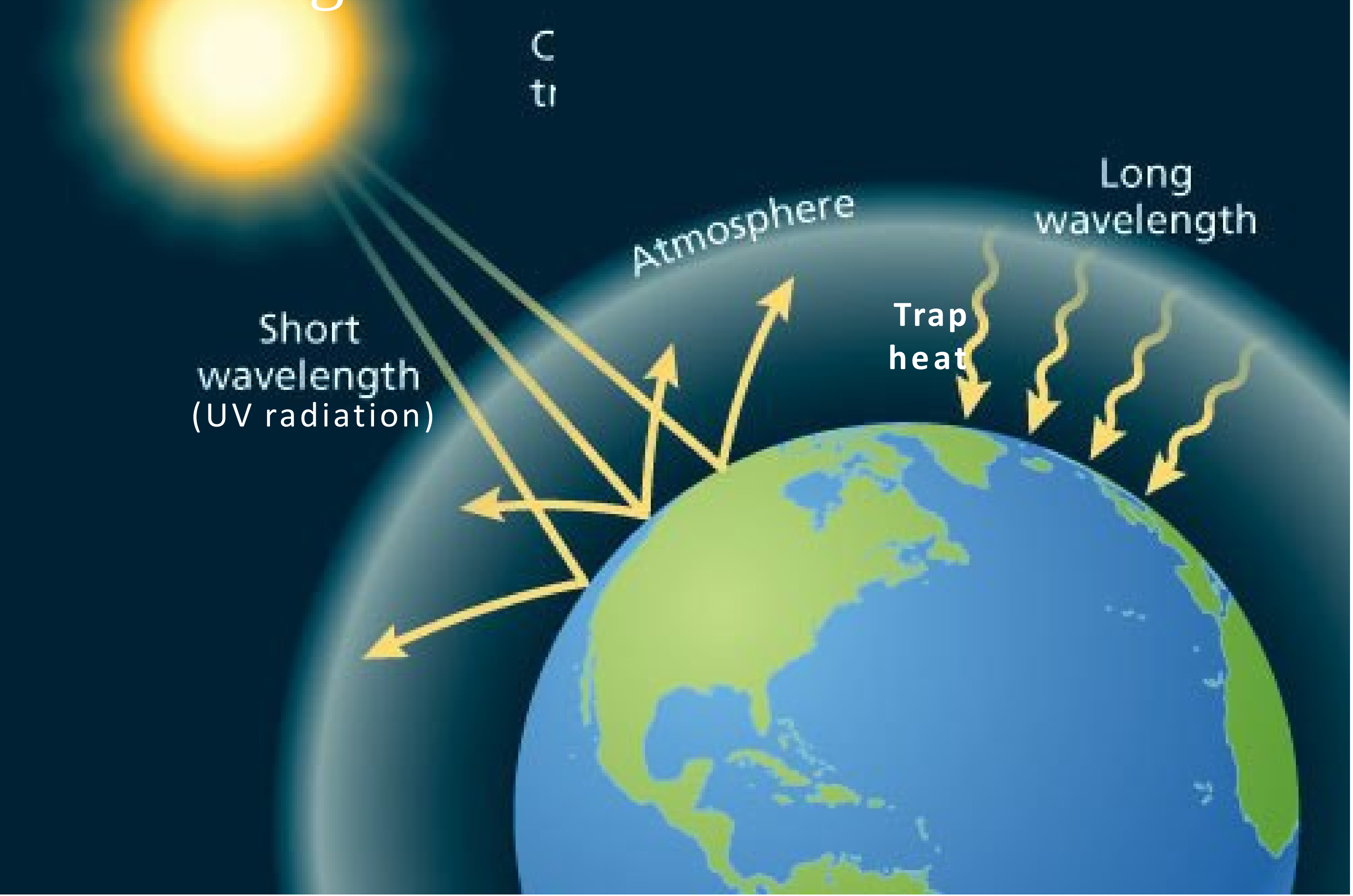
Gas	Mixing ratio	Source
Water vapour	10,000 to 2 ppmv	Natural
Methane	1.7 ppmv	Biogenic
Nitrous oxide	310 ppbv	Biogenic
Carbon monoxide	50-500 ppbv	Anthropogenic
Ozone	10 ppbv to 10 ppmv	Photochemical
Halocarbons	Few hundred pptv	Anthropogenic

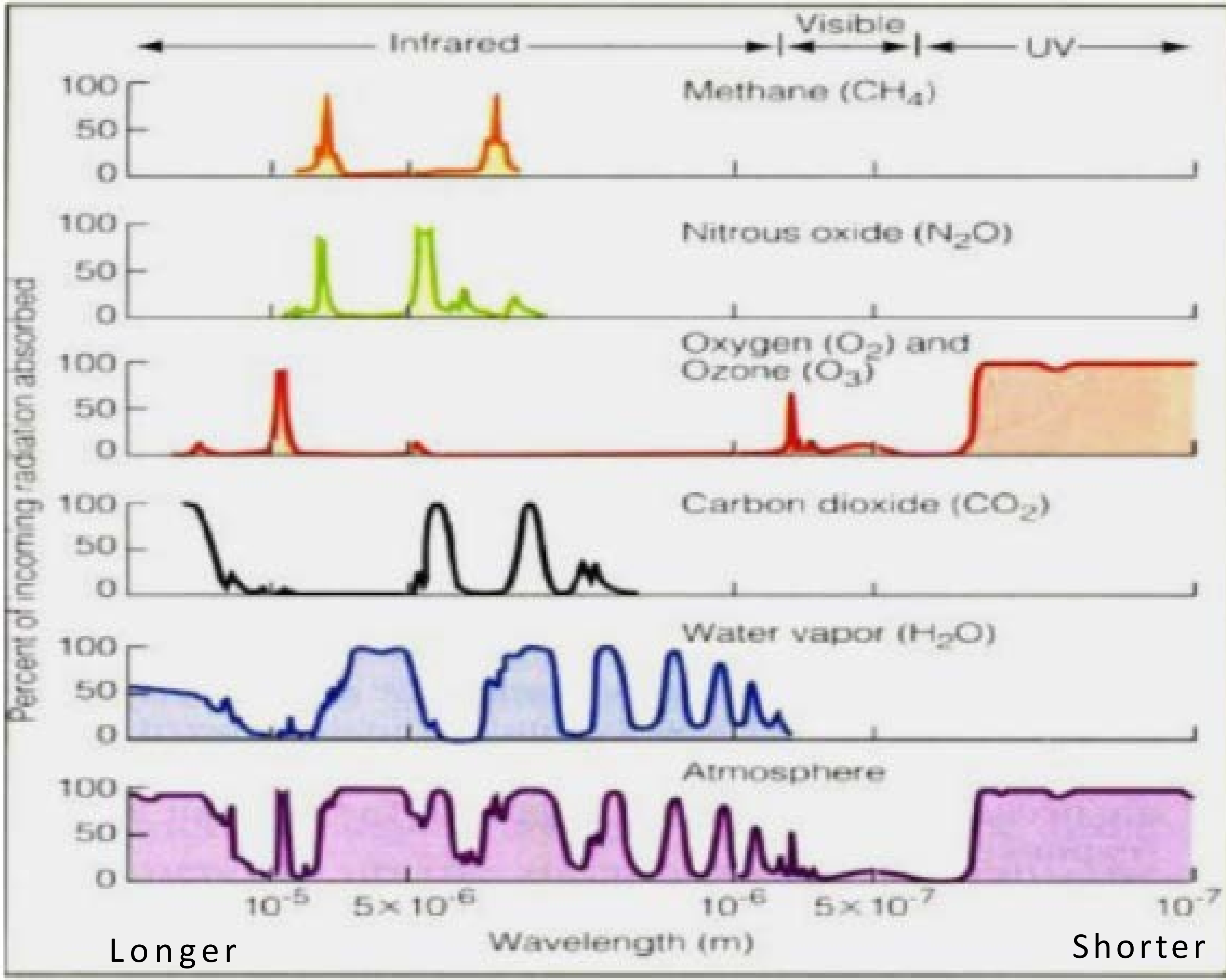
Composition of the earth's atmosphere

- Trace gases = less than 1% of the atmosphere
- H_2O, CO_2, CH_4, SO_2, and N_2O etc. all have an important property!
  - The ability to **absorb thermal energy (heat)** emitted by the earth
  - Warms the atmosphere
  - 'The greenhouse effect'
- These gases have influence on:
  - Short-term weather
  - Long-term climate
  - Called 'greenhouse gases' (GHGs)



GHGs absorb longer infrared (thermal) wavelengths




Infrared
Visible
UV
Methane (CH_4)
Nitrous oxide (N_2O)
Oxygen (O_2) and
Ozone (O_3)
Carbon dioxide (CO_2)
Water vapor (H_2O)
Atmosphere
Percent of incoming radiation absorbed
100
50
0
10^{-5}
5×10^{-6}
10^{-6}
5×10^{-7}
10^{-7}
Wavelength (m)
Longer
Shorter

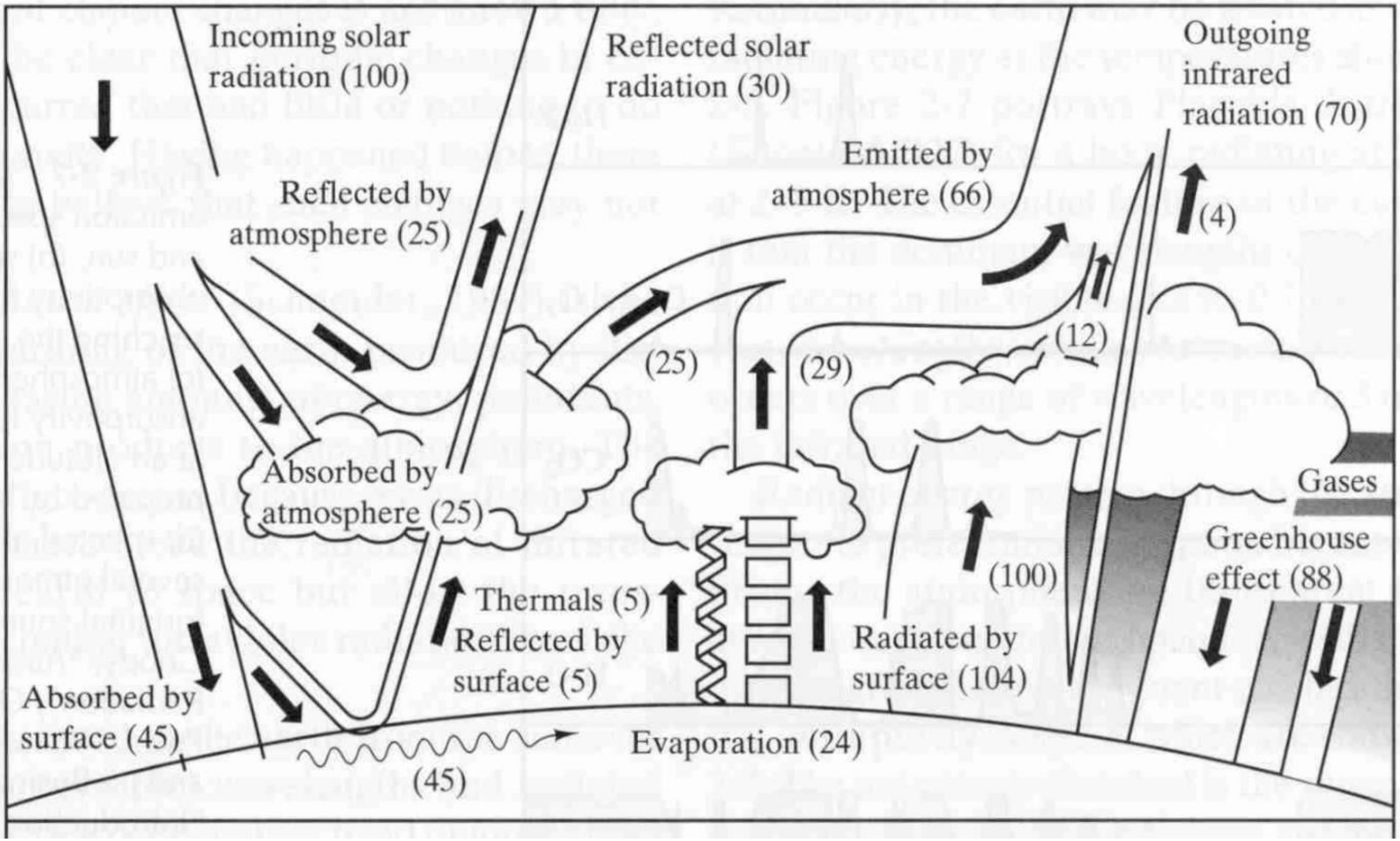
Greenhouse Effect

- GHGs allow shorter (UV) wavelengths to the earths surface
- The reflected longer infrared (thermal) wavelengths are absorbed by GHGs
- Recapturing some of the radiated heat

- Some GHGs are important to regulate the earths temperature
- But! GHGs are so thermally potent that even proportionately small amounts can cause temperature rise

Global warming

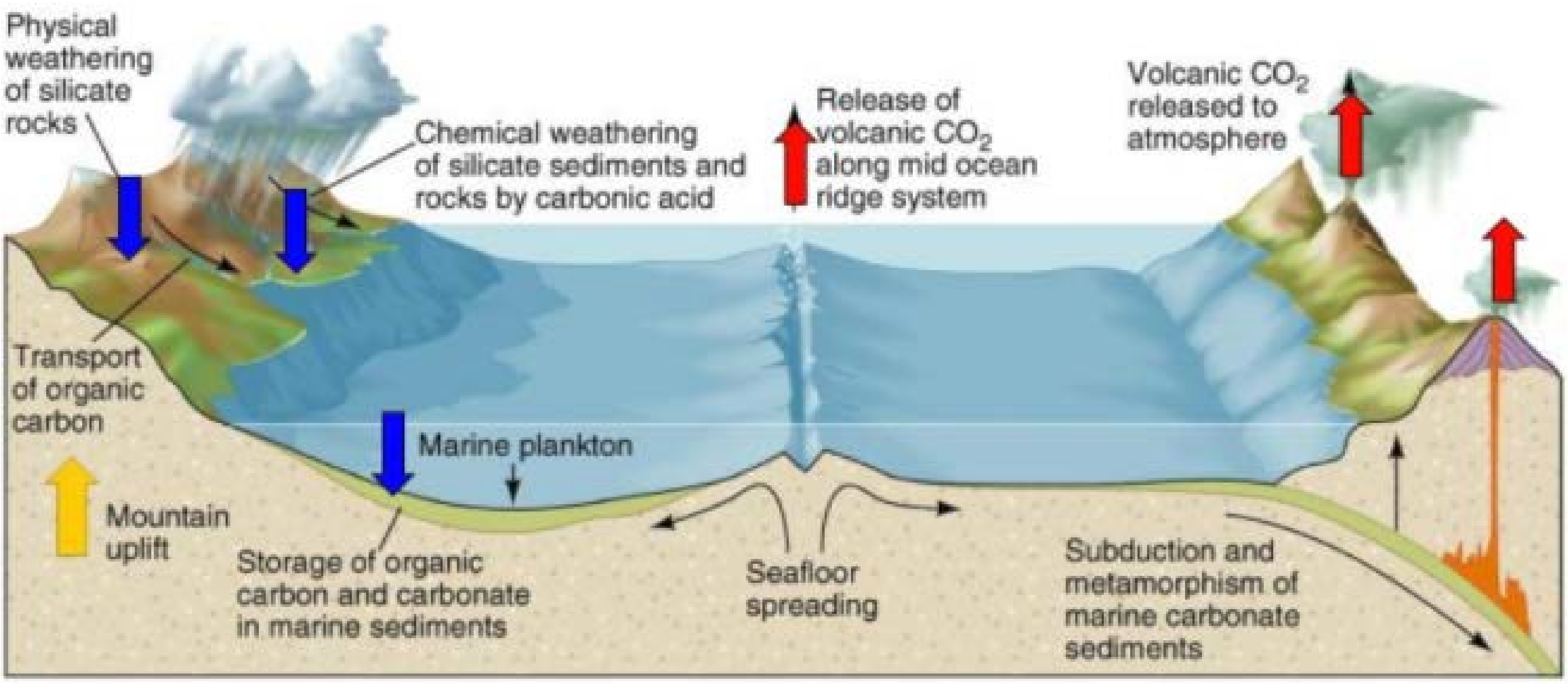
- Energy exchange between the Sun, Earth, Atmosphere & Space



(adapted from Sources and Control of Air Pollution, Prentice Hall, 1999, p78)

The CO_2 Cycle as Earth's Thermostat

- ⬆ Large quantities of CO_2 in the atmosphere resulting in temperature increase
- ⬇ Causes increased chemical weathering and marine carbonate deposition which lowers atmospheric CO_2



Sources of greenhouse gases

- Human impacts:



- Natural impacts:


Primary greenhouse gases

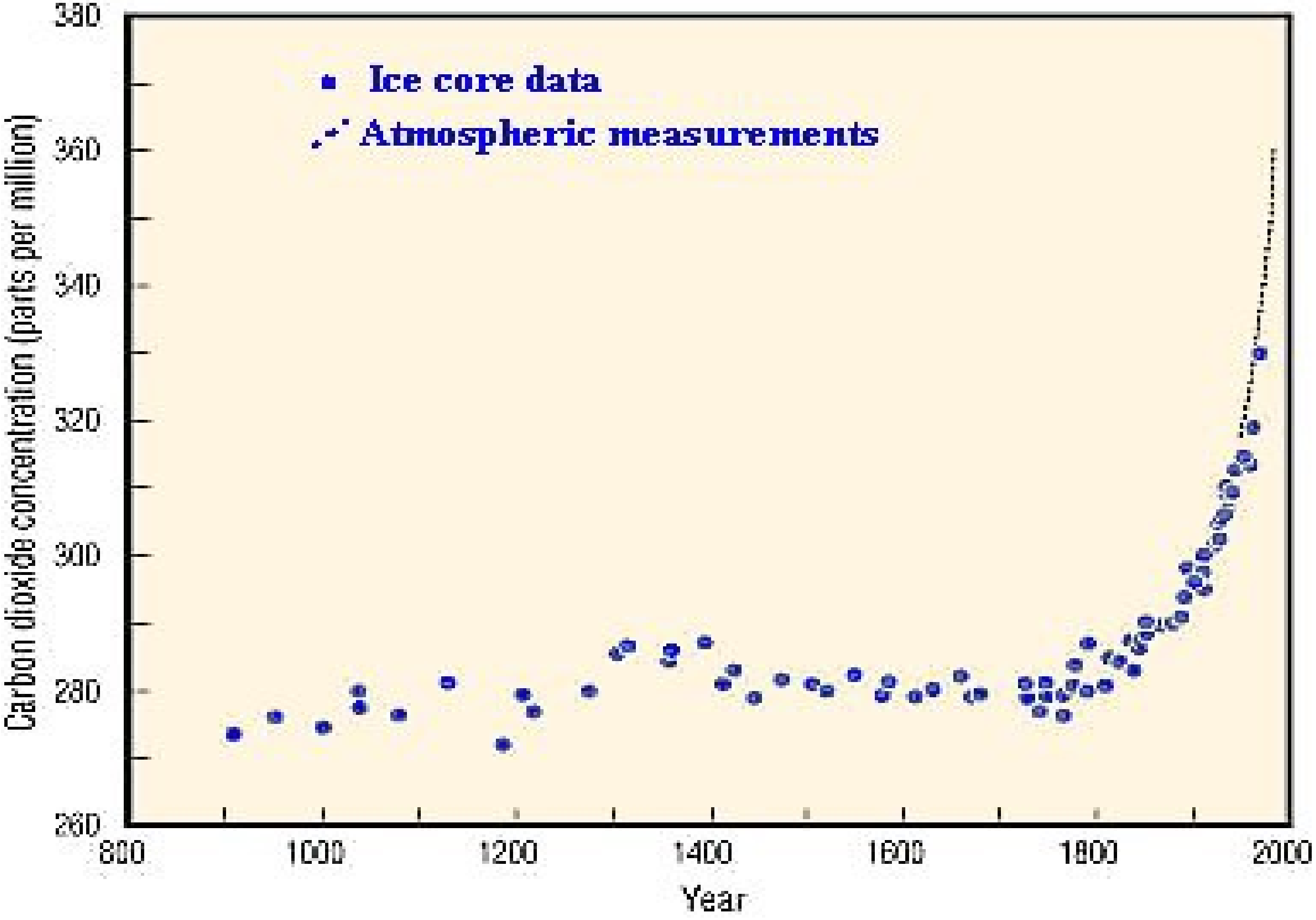
Gas	Greenhouse effect contribution
Water vapour (H_2O)	~60 %
Carbon dioxide (CO_2)	~26 %
Ozone (O_3)	~8 %
• Methane (CH_4) • Nitrous oxide (N_2O) • Other	~6 %

Not changing

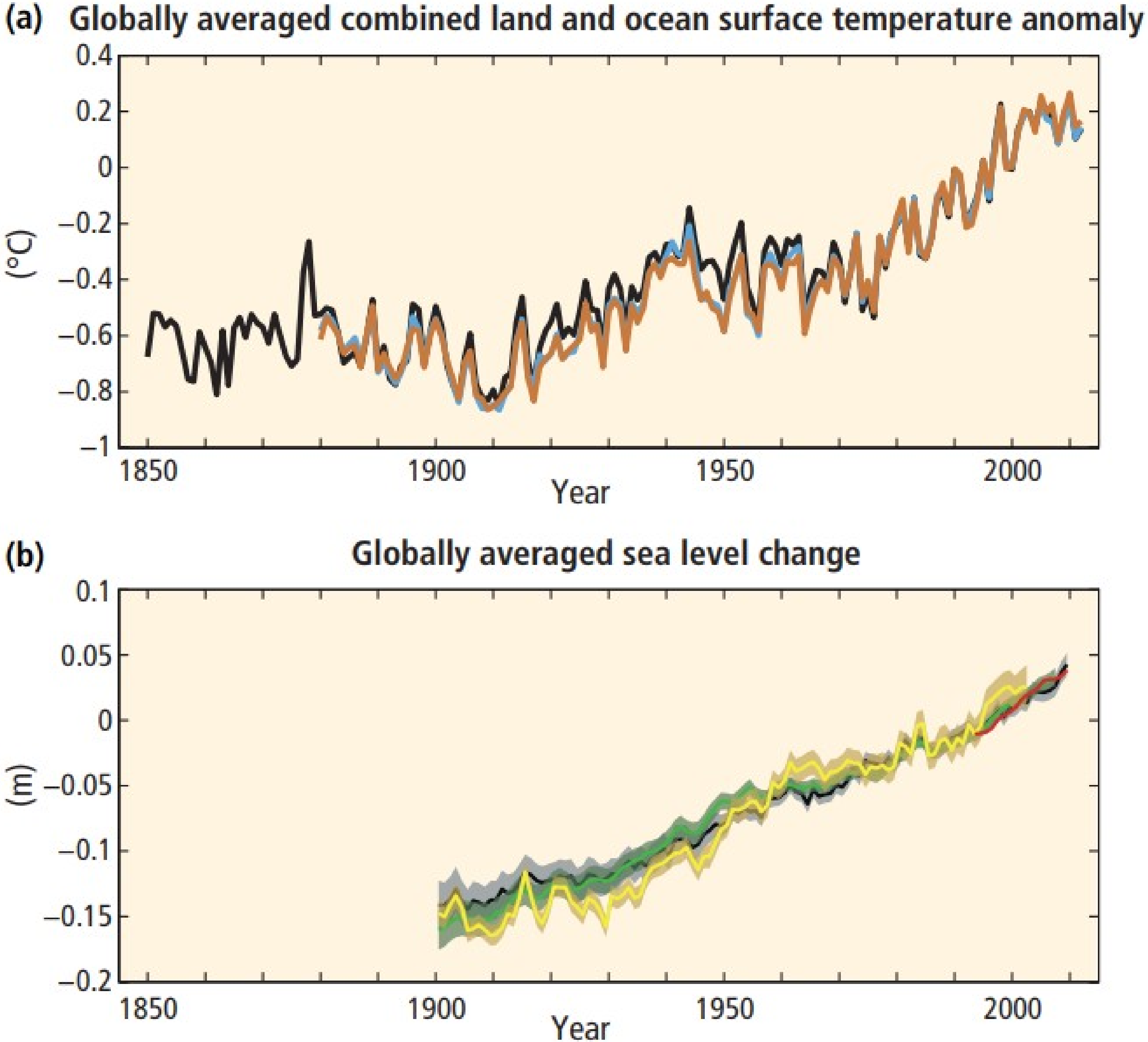
Significant GHGs in terms of global warming

GHG	Sources	Sinks	Importance for climate
Carbon dioxide	• Burning of fossil fuel • Land-use change (deforestation)	• Ocean uptake • Photosynthesis	Absorbs infrared radiation; affects stratospheric O_3
Methane	• Biomass burning • Rice paddies	• Reactions with OH • Microorganisms uptake by soils	Absorbs IR; affects tropospheric & stratospheric O_3; produces CO_2
Nitrous oxide	• Biomass burning • Fossil fuel combustion • Fertilizers	• Removal by soils • Stratospheric photolysis and reaction with oxygen	Absorbs IR; affects stratospheric O_3
Ozone	• Photochemical reactions involving O_2	• Catalytic chemical reactions involving NO_x species	Absorbs UV & IR radiation
CFC	• Industrial production	• Dissociated in stratosphere	Absorbs IR; affects stratospheric O_3
Sulphur dioxide	• Volcanoes, coal and biomass	• Dry & wet deposition	Forms aerosols, which scatter solar

CO_2 concentration

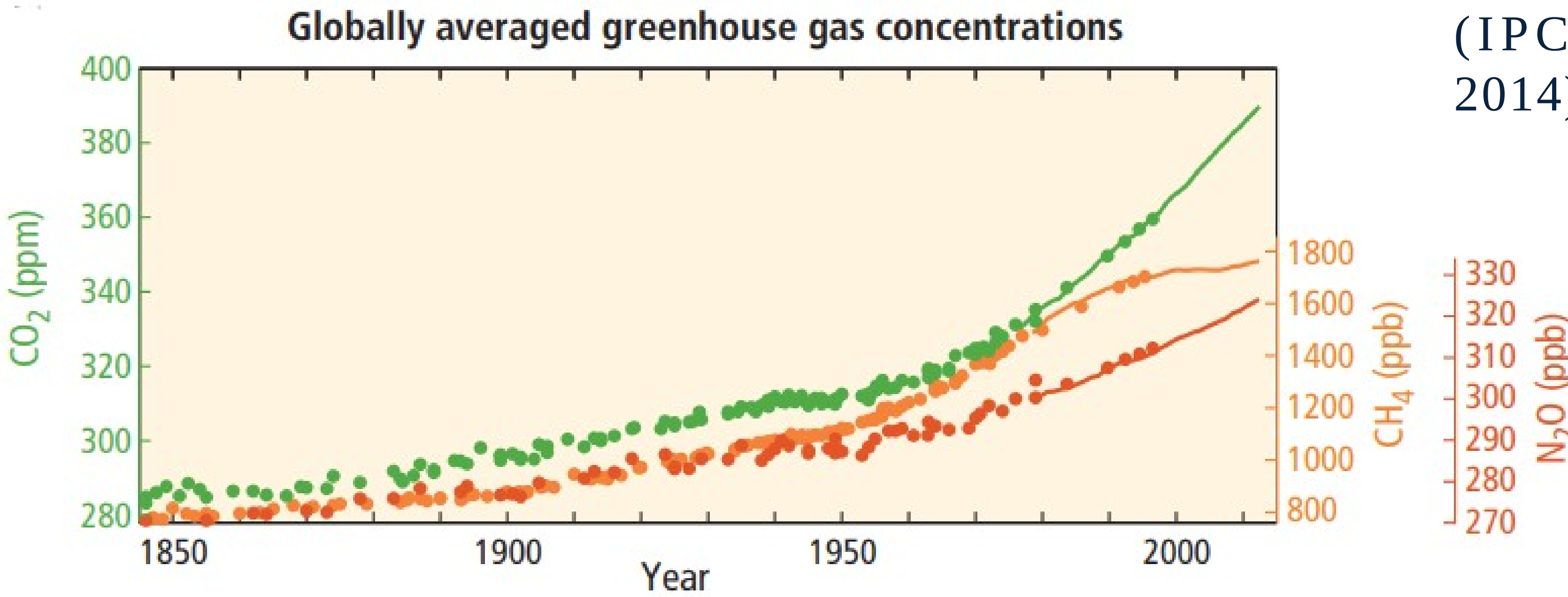


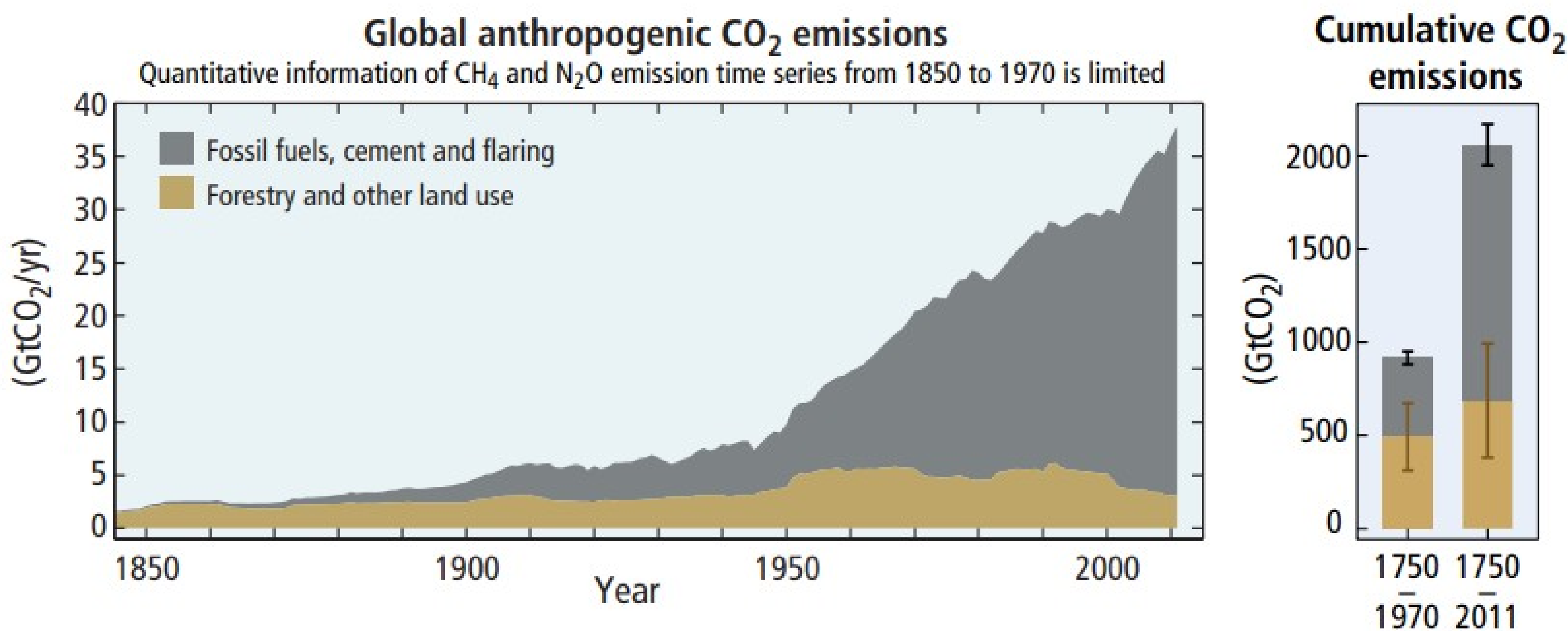
Sharp increase since the industrial revolution



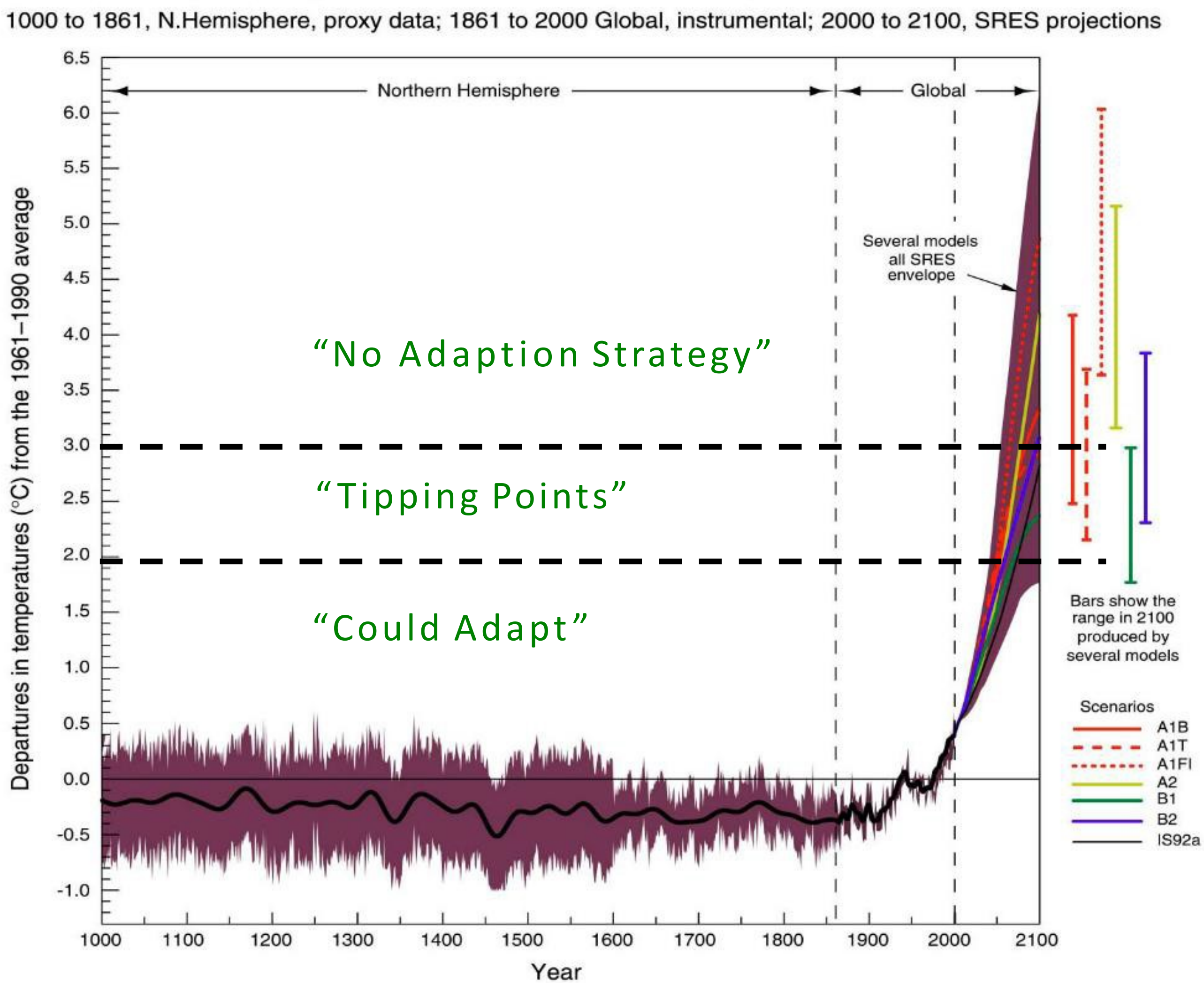
Intergovernmental Panel on Climate Change (IPCC) 2014

(IPCC 2014)


Globally averaged greenhouse gas concentrations
CO_2 (ppm)
CH_4 (ppb)
N_2O (ppb)
400
380
360
340
320
300
280
1800
1600
1400
1200
1000
800
330
320
310
300
290
280
270
1850
1900
1950
2000
Year


Global anthropogenic CO_2 emissions
Quantitative information of CH_4 and N_2O emission time series from 1850 to 1970 is limited
Fossil fuels, cement and flaring
Forestry and other land use
($GtCO_2$/yr)
40
35
30
25
20
15
10
5
0
1850
1900
1950
2000
Year
Cumulative CO_2 emissions
($GtCO_2$)
2000
1500
1000
500
0
1750–1970
1750–2011

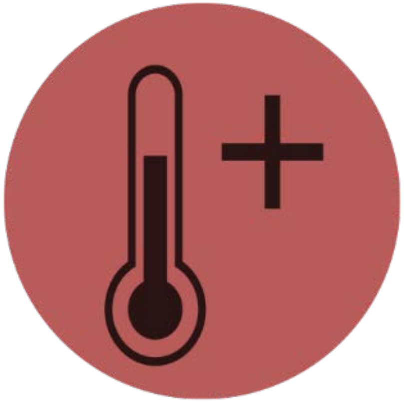
Temperature projection



Expected consequences of increased GHG concentration is: Climate Change

GLOBAL WARMING

- Is the increase of the Earth's average surface temperature due to a build-up of greenhouse gases in the atmosphere.



CLIMATE CHANGE

- Is a broader term that refers to long-term changes in climate, including average temperature and precipitation.

Main impacts of climate change

- Sea level rise
  - Global sea level has increased by 0.19m between 1910 and 2010
- Increase in sea surface temperature
  - Global average increase of 0.11^{0}C between 1971 and 2010
- Change in precipitation
  - Intense flooding
  - Severe droughts
- Change in El Nino intensity
  - Flooding, droughts, wild fires and famines
- Ocean acidification
  - The acidity of the oceans has decreased by 0.1 on the pH scale since the beginning of the industrial era).

United Nations Framework Convention on Climate Change (UNFCCC)

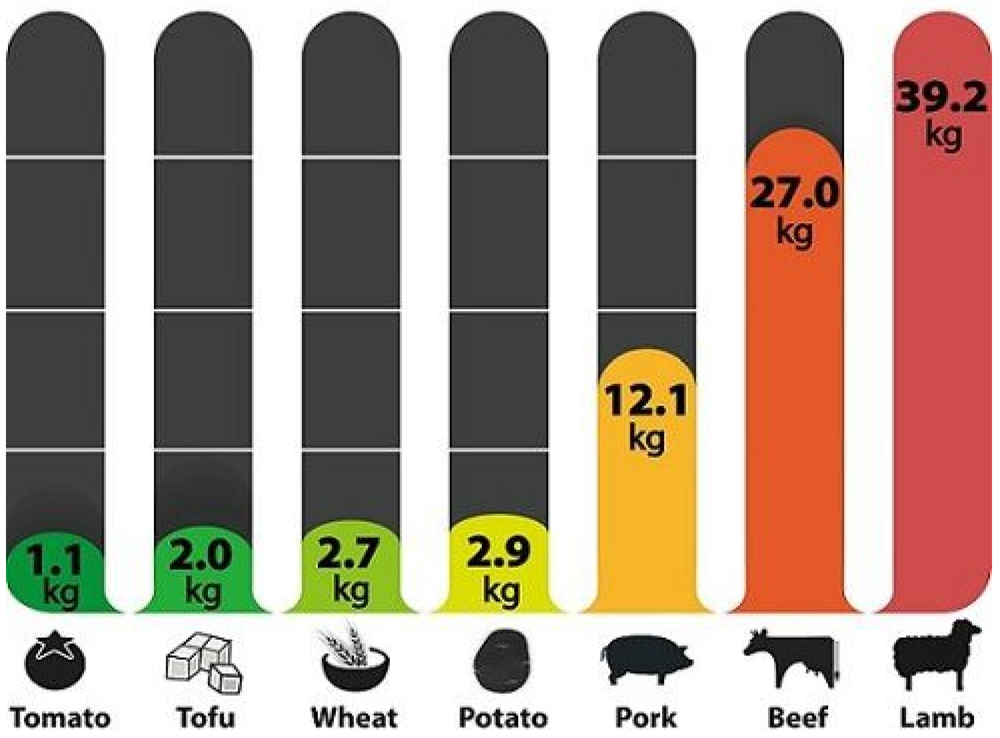
- 1997 – Kyoto Protocol
- Framework to:
  - Stabilise GHG emissions to prevent human interference with the climate system
  - Set emission targets for industrialized countries
  - **“limit global temperature rise to 2 degrees”**
  - **“our current path will lead to a 6 degree increase”**
    - *- UN Secretary-General (2013)*
- 2015 – Paris Agreement
  - All UNFCCC participants sign the ‘Paris Agreement’
  - Replacing Kyoto Protocol
  - *“limit warming ‘well below’ 2 degrees…”*

What is carbon footprint?

- Also known as:

- Carbon Footprint (CF)
- Carbon Inventory
- Greenhouse Gas Inventory
- Climate Change footprint

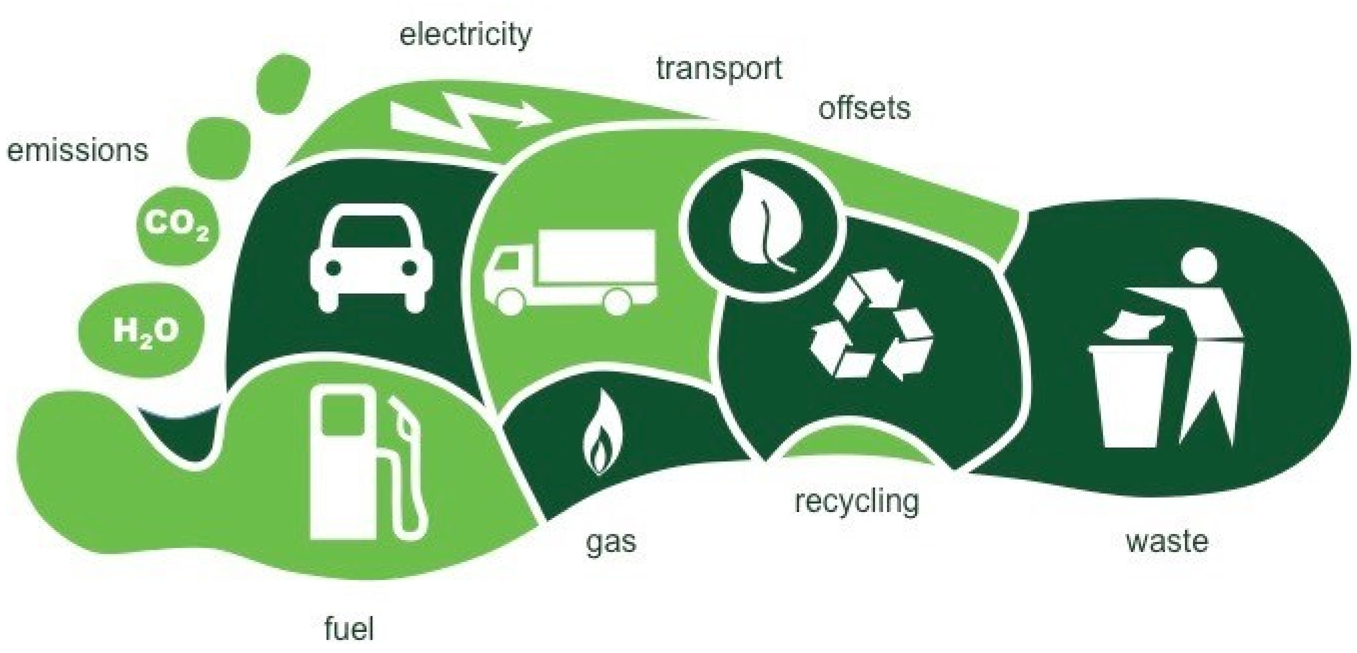
(kg CO_2 equivalent)



Includes: growing, rearing, farming, processing, transporting, storing, cooking and disposing of the food on your plate.

Carbon Footprint

- Total amount of GHGs produced to support human activity
- Both directly and indirectly
- Units: equivalent tonnes of carbon dioxide (CO_2)
- For an individual, activity, industry, country etc.



Carbon Footprint = Sum of:

1. All fossil fuel consumption (including petrol, electricity, natural gas)

2. All transportation (besides human-powered activities like walking and cycling)

3. All emissions associated with consumables

Carbon footprint calculation

- Considers all GHG emission from each activity

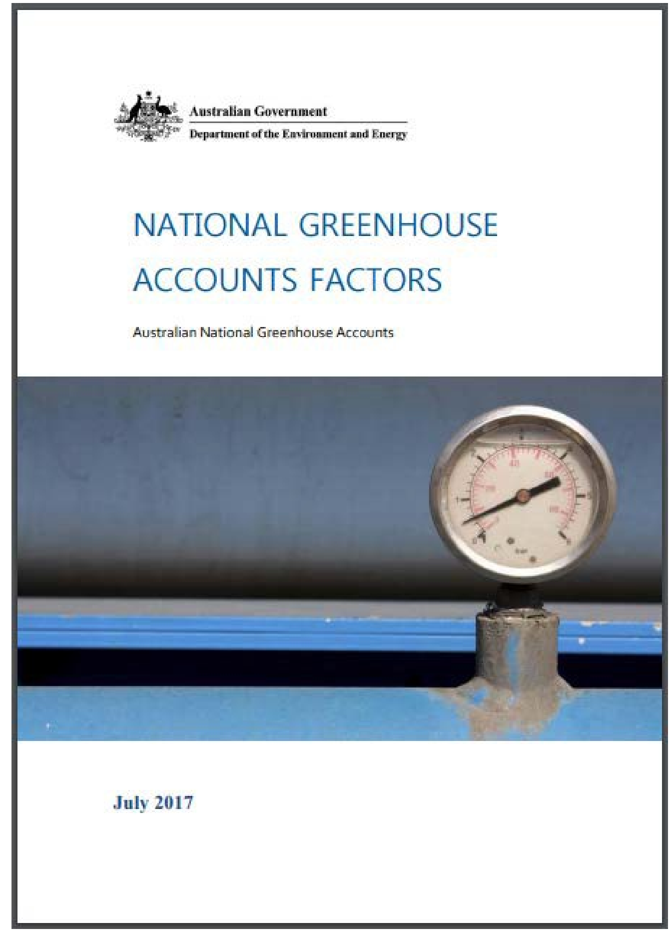
Method

1. Define boundaries
   - Identify type of emission (direct or indirect)
2. Estimate GHG emission amount
   - *Using Emission Factors*

     or
   - Direct calculation
1. Convert all GHG amounts to CO_2 equivalent amount
   - Using *Global Warming Potent Index*

Australian National Greenhouse Accounts (NGA)

- Department of the Environment and Energy
- NGA Factors are used by companies and individuals to estimate greenhouse gas emissions.



Defining boundaries

Carbon Footprint		
Scope 1: Direct Emissions	Scope 2: Indirect Emissions (Purchased energy)	Scope 3: Other Indirect Emissions

Scope 1: Direct Emissions (Point Source)

- Relatively easy
- Point of emission release
  - Combustion sources
  - Site owned vehicles
  - On-site electrical generation
  - Manufacturing process activity
  - Mining activity
  - On-site waste disposal

Scope 2: Indirect Emissions

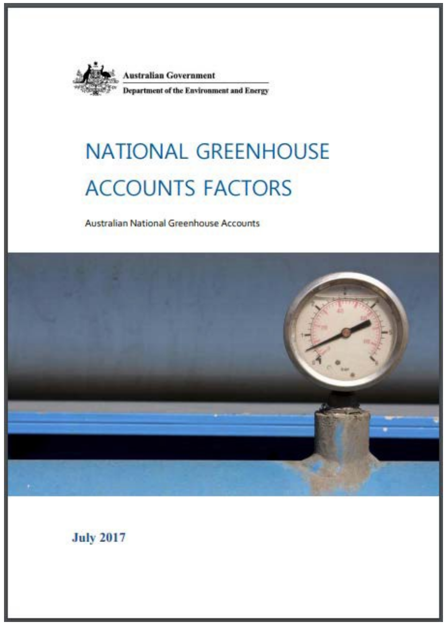
- Energy that is purchased and consumed by an organisation
- Relatively easy:
  - Emissions from consumption of purchased utilities:
    - Typically electricity
    - Could be steam or high temperature hot water
    - Could be negative (e.g. electricity from solar panel)
- Scope 2 emissions are physically produced by the burning of fuels at the power station

Scope 3: Other Indirect Emissions

- Can be very difficult:
  - Embodied energy in goods & services
  - Transportation of purchased material or goods
  - Employee business travel
  - Employee commuting impacts
  - Off-site waste disposal
- Outsourced work

- Scope 3 has various challenges
- Boundary issues
- Can be a magnitude higher than Scope 1 and 2

Emission Factors



- Activity – specific
  - Energy
  - Industrial processes
  - Waste emissions
  - Agriculture
  - Land use and forestry
- The activity & scope determine the emission factor used
- The scope that emissions are reported under is determined by whether the activity is
  - within the organisation’s boundary (direct-scope 1) or
  - outside it (indirect scope 2 or 3)

Energy Sector Emissions

Example

- CO_2 generation by fossil fuel combustion
- Quantity of gas depends on:
  - Carbon content of fuel
  - Degree of combustion
- Other GHGs are also generated

- Emissions Factor estimates CO_2 equivalent based on GJ of energy produced

Energy Sector Emissions Scope 1 (DIRECT)

Scope 2 & 3 (INDIRECT)

Fuel combusted	Energy content A	Point source emissions factor B	Full fuel cycle emissions factor C
	GJ/t	kg CO_2-e/GJ	kg CO_2-e/GJ
Solid Fuels			
Black coal – NSW Electricity Generation	•27.0 (washed) 23.2 (unwashed)	90.3	98.1
Black coal – NSW other uses	•27.0 (washed) 23.2 (unwashed)	90.3	97.0
Black coal – Qld Electricity Generation	•27.0 (washed) 21.9 (unwashed)	91.2	93.9
Black coal – Qld other uses	•27.0 (washed) 21.9 (unwashed)	90.3	94.9
Brown coal	10.0	92.0	92.5
Coal used in steel industry	30.0	91.8	112.8
Brown Coal Briquettes	22.1	105.0	115.3
Coke	27.0	119.5	130.9
Wood and wood waste (dry) (CO_2 not counted)	16.2	1.4 (if used in boiler) 14.5 (if used in residential)	1.4 (if used in boiler) 14.5 (if used in residential)
Bagasse as crushed (CO_2 not counted)	9.6	1.4 (if used in boiler)	1.4 (if used in boiler)
Gaseous Fuels			
Coal by-products (gaseous)	18.1 MJ/m^3	37.0	48.4
Natural gas	Refer table 2	Refer table 2	Refer table 2
Town gas	Consumption measured in GJ	59.4	59.4

CO_2 Equivalent

- A term for describing different GHGs in a common unit
- The amount of CO_2 which would have the **equivalent** global warming impact
  - Estimated based on a 100 year period
- Allows analysis and comparison across different sectors & activities

- Uses a **Global Warming Potential Index** for each non-CO_2 gas

Global Warming Potential Index

- Used to convert relevant CO_2 gases to a carbon dioxide equivalent (CO_2-e)

Greenhouse Gas	Global Warming Potential Index
Carbon Dioxide, CO_2	1
Methane, CH_4	21
Nitrous oxide, N_2O	310
HFC 134a	1,300
Sulfur hexafluoride	23,900

tonne CO_2-e = tonne of gas x GWP_{gas}

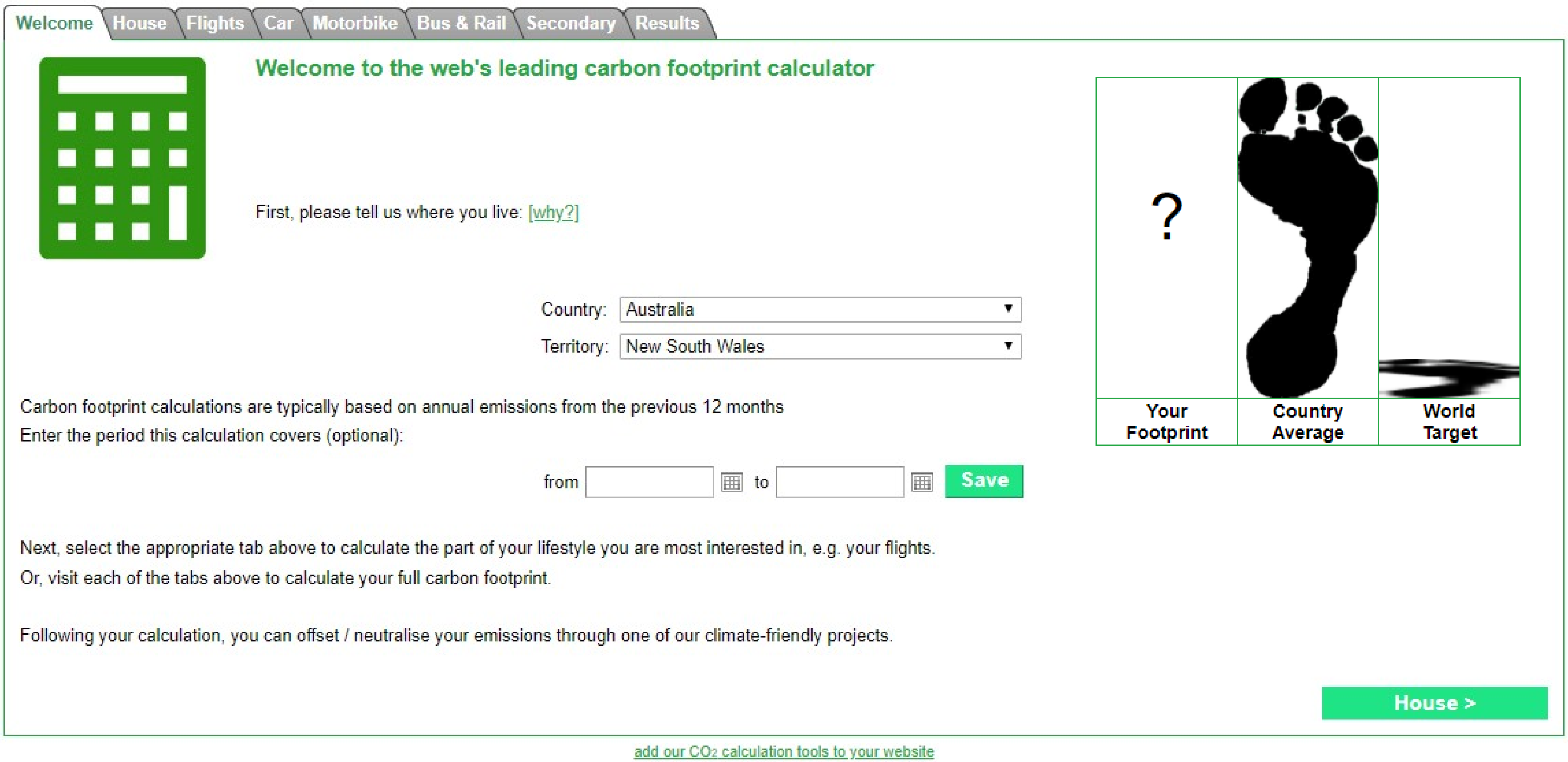
CO_2 Equivalent

EXAMPLE: Find

GHG	Emissions (tonne)	Global Warming Potential Index	Metric tonne CO_2-e
Carbon Dioxide	10,000	1	10,000
Methane	500	21	10,500
HFC 134a	1.0	1300	1300
SF_6	0.06	23,900	1434
		Total	**23,234**

Online Carbon Footprint Calculator

- https://www.carbonfootprint.com/calculator.aspx



Reducing Carbon Footprint

- Efforts to reduce a carbon footprint of an individual, household or company usually involves *reducing*, *reusing* and *recycling*
- Fundamental changes in industry:
  - GHG, carbon neutrality, energy conservation are all part of a new facilities vocabulary
  - GHG and carbon management need to be part of the value-chain decision making
    - Construction and Major Renovation
    - Operations and Maintenance and Repair
    - Disposition

Further reading

- https://www.climatechangeinaustralia.gov.au/en/
- www.climatechange.gov.au
- *Factors and Methods Workbook* – On Moodle
- https://www.carbonfootprint.com/calculator.aspx