Atmosphere and climate change

Topic 6 · SL and HL

One year and a long-term target

Paris Agreement

Adopted December 2015; signing opened April 2016.

Well below 2 °C; pursue efforts towards 1.5 °C.

WMO report on 2024

Calendar year 1.55 ± 0.13 °C above 1850–1900.

One annual value does not establish a long-term target breach.

Composition and layers

Dry air

About 78% nitrogen, 21% oxygen and 0.9% argon.

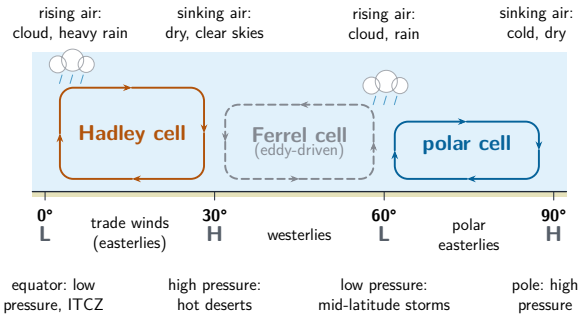
NOAA global 2024 CO_2: about 422.8 ppm; water vapour excluded from dry air.

Temperature profile

Troposphere: most weather; temperature usually falls upwards.

Stratosphere: **ozone** absorbs UV; temperature rises upwards.

Three circulation cells



one hemisphere, idealised zonal mean; heights not to scale

Link rising and sinking air to pressure and surface winds.

Heat and surface winds

Pressure and motion

Equatorial ascent; subtropical descent; ascent near 60°; polar descent.

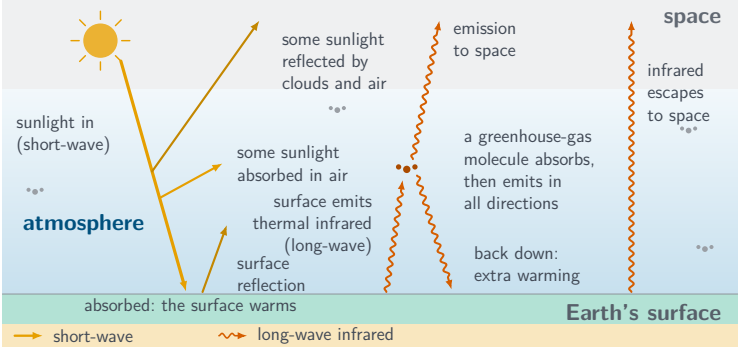
Hadley and polar cells redistribute heat; Ferrel circulation is indirect and eddy-driven.

Wind directions

Rotation deflects right in the north and left in the south.

Trade/polar easterlies; mid-latitude westerlies. Names describe where winds come from.

Radiation and greenhouse gases



Selected pathways, not a complete flux budget: both atmosphere and surface absorb solar radiation.

Trace the energy mechanism

Solar and surface radiation

Incoming solar includes visible, near-infrared and **ultraviolet**.

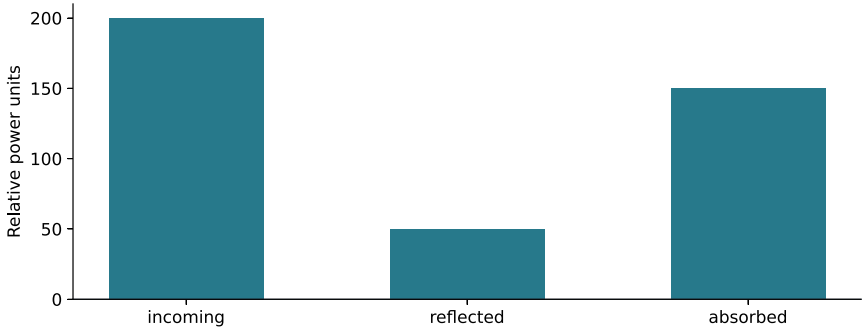
A warmed surface emits new thermal-infrared photons.

Atmospheric interaction

Greenhouse gases absorb and emit infrared in all directions.

Some infrared escapes; downward emission contributes to surface heating.

A surface albedo model



200 incoming − 50 reflected = 150 absorbed; this surface boundary excludes atmospheric absorption.

Albedo and absorbed power

1. **Invented givens.** Incoming 340 W/m^2, **albedo** 0.30.
2. **Reflected.** $340 \times 0.30 = 102$ W/m^2.
3. **Absorbed.** $340 - 102 = 238$ W/m^2.

Decision

This is not the complete surface heat budget; infrared, sensible and latent heat also matter.

Compare gases and aerosols

Gases

CO_2: fossil fuels, cement and land use; no single lifetime.

CH_4: leaks, ruminants, rice and wastes; roughly decade-scale perturbation decay.

Other agents

N_2O from nitrogen cycling; halocarbon effects depend on compound.

Water vapour is modelled as a feedback; aerosols can scatter or absorb sunlight.

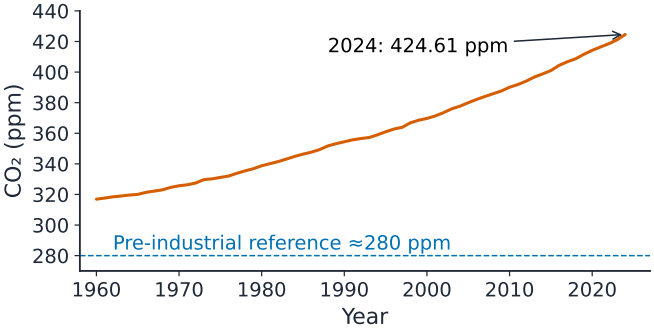
A stated-horizon comparison

1. **Assigned metric.** Invented 100-year methane factor = 28 per equal mass of CO_2.
2. **Assigned emission.** 2 tonnes methane $\times$ 28 = 56 tonnes CO_2-equivalent.
3. **Interpret.** Time-integrated comparison, not lifetime or instantaneous heat.

Decision

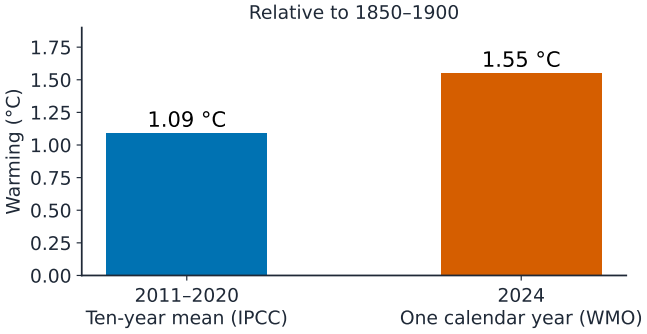
Equal CO_2-equivalent values do not mean identical time profiles or interchangeable policy needs.

Measured concentration is not annual emissions



NOAA Mauna Loa station annual means, 1960–2024; global averages and seasonal peaks differ.

Two reported warming statistics



Different averaging periods: do not infer a warming rate or Paris breach from these two bars.

Independent lines of evidence

Instruments and change

Stations, satellites, oceans, glaciers and biological timing.

Sea level: thermal expansion and land-ice loss; floating sea ice has little direct effect.

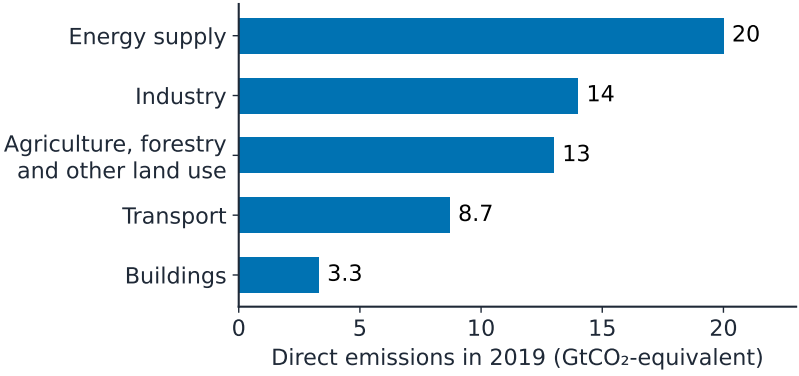
Past climates

Ice-core bubbles preserve ancient air; isotopes provide temperature-related proxies.

Tree rings, pollen and sediments require calibration and dating; not all directly measure CO_2.

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Direct sector emissions in 2019



IPCC rounded estimates total 59 $GtCO_2e$; allocating electricity to end users changes sector shares.

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State the accounting boundary

Different measures

Annual versus cumulative; total versus per person.

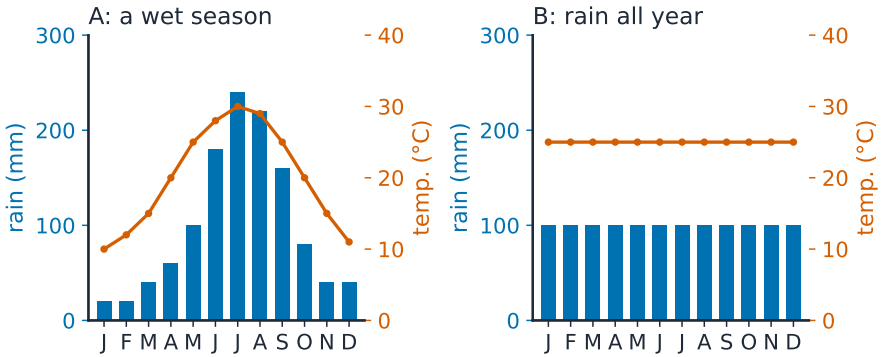
Territorial versus consumption-based; fossil CO_2 versus all greenhouse gases.

Planetary boundary

Common CO_2 control value: 350 ppm; 2024 global value exceeds it.

Different from a Paris temperature target or proof every **tipping point** is crossed.

Read a monthly climate graph



Invented sites: bars show rain; lines show temperature.

Read climate distributions

Invented monthly observations

A: rainfall varies 20–240 mm/month, total 1200 mm/year; temperature 10–30 °C.

B: rainfall 100 mm/month, temperature 25 °C throughout; same 1200 mm/year.

Interpret the pattern

A has a 20 °C monthly temperature range; B has 0 °C.

Equal annual rainfall does not establish equal dry-season stress or runoff.

Ecosystems: mechanism and context

Great Barrier Reef, 2024

Marine heat stress caused widespread bleaching.

Loss of symbiotic algae reduces energy supply; bleaching need not mean immediate death.

Range and productivity

Some cooler regions gain growing-season length, with water/nutrient limits.

Fragmentation and movement rates constrain species responses.

Tuvalu and unequal vulnerability

Named adaptation evidence

UNDP reported handover of 7.3 ha reclaimed land in October 2024.

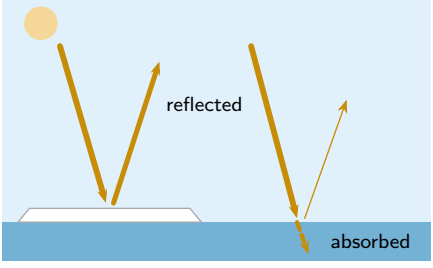
Raised land can reduce specific coastal risks.

Evaluate limits

Exposure, sensitivity and adaptive capacity vary within societies.

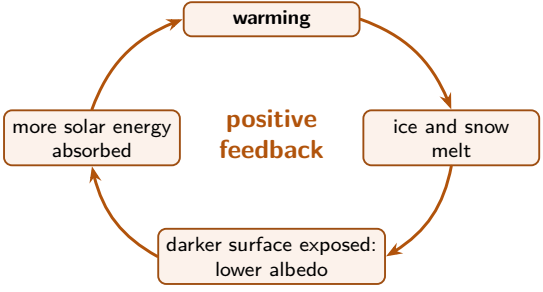
Maintenance, future sea level, ecology, rights and finance remain important.

Ice-albedo amplification



ice and snow
high albedo:
most sunlight reflected

open water
low albedo:
most sunlight absorbed



amplifies the change;
not a beneficial outcome

Positive means amplifying, not beneficial; a feedback alone does not locate a tipping threshold.

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Feedback is not a dated collapse prediction

Amplifying and stabilising

Ice loss, water vapour and **permafrost** carbon can amplify warming.

Warmer bodies emit more; plant uptake is constrained by water, nutrients and disturbance.

Tipping elements

Component changes may become self-sustaining.

State mechanism, uncertainty and timescale; thresholds are not one universal date.

Mitigation and adaptation

Mitigation

Reduce emissions or increase net atmospheric removal.

Clean energy, methane-leak reduction and protecting carbon stores.

Adaptation

Reduce exposure or vulnerability to impacts.

Flood defences, warnings and changed planting dates; some actions do both.

Avoided emissions versus removal

Point-source capture

Capturing fossil or cement process CO_2 avoids some new emissions.

Check residual releases, energy, upstream emissions and durable storage.

Potential removals

DAC with storage or suitable biomass/soil pathways need a negative net balance.

Permanence, leakage, saturation, land and energy requirements matter.

Structural and non-structural adaptation

Structural

Flood barriers, raised buildings, drainage and water storage.

Check maintenance, displaced erosion and residual risk.

Non-structural

Warnings, zoning, standards and emergency planning.

Access, communication, compliance and capacity determine results.

Sponge approaches and national plans

Cities

Permeable surfaces, planted storage and wetlands slow runoff.

Capacity, saturation and blocked outlets limit performance.

Planning

NAPs: medium/long-term priorities, delivery and monitoring.

NAPAs: earlier urgent needs of least-developed countries; not the same as NDCs.

Climate treaties and implementation

Frameworks

UNFCCC 1992; Kyoto 1997 commitments for relevant participating Parties.

Paris successive NDCs, transparency and collective assessment.

Judgement

Targets and procedural duties differ from achieved reductions.

Net-zero global CO_2 pathways are not a universal 2050 all-gas legal deadline.

Carbon prices and cooperation

Tax versus absolute cap

Tax fixes price; response quantity is uncertain.

Absolute-cap trading limits covered quantity; price varies.

Distribution and sovereignty

Revenue use, monitoring, offsets and trade boundaries matter.

Domestic follow-through, finance and technology support international cooperation.

Three kinds of adaptation

structural
flood defences, raised buildings, drainage, water storage

non-structural
early warnings, zoning, building standards, planting dates, plans

ecosystem-based
restore mangroves and wetlands (need space and conditions)

compare lifecycle cost, who benefits and shifted harm: a seawall can move erosion along the shore

Ecosystem-based: restored mangroves

Climate treaties



COP30 met in Belém in 2025

Radiation and ozone

Protective stratosphere

O_2/**ozone** absorb all UV-C and much UV-B; much UV-A reaches ground.

Shorter wavelength means higher photon energy.

Distinct problems

More UV-B damages DNA, eyes, crops and phytoplankton.

Ground-level ozone is the same molecule in a harmful secondary-pollutant context.

Dynamic balance and depletion

Molecules change continually

Ozone formation and destruction rates can balance.

Stable CFCs reach the **stratosphere**; UV releases reactive chlorine.

Polar conditions

Catalysis regenerates chlorine; cold cloud surfaces and spring sunlight matter.

An **ozone hole** is severe seasonal depletion, not empty atmosphere.

Montreal, recovery and Kigali

Controls and evidence

Montreal 1987 controls ODS; finance, alternatives and monitoring support action.

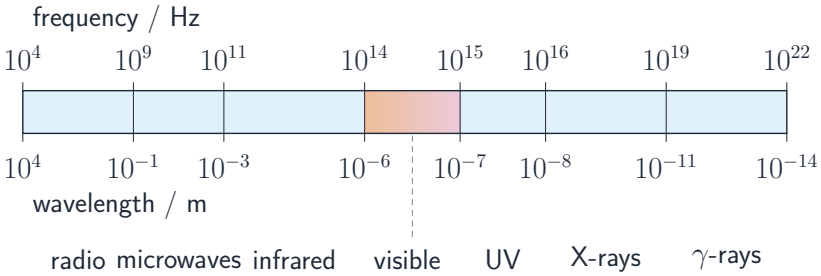
2022 assessment projects conditional recovery, not guaranteed exact dates.

Different metrics

Regional Antarctic loss differs from a global planetary-boundary control.

Kigali 2016 phases down HFCs; HCFC phase-out is a separate ODS measure.

The electromagnetic spectrum



UV-B and UV-C damage living cells; **ozone** absorbs them

AHL: Parcel versus environment

1. **Invented start.** Both 20 °C; dry parcel cools 9.8 °C/km, environment 6.5 °C/km.
2. **At 1 km.** Parcel 10.2 °C; environment 13.5 °C.
3. **Tendency.** Colder parcel tends to sink back without continued forcing.

Decision

Environmental, dry-adiabatic and saturated rates differ; inversions can suppress mixing.

AHL: Long-term forcings and living systems

Orbital cycles

Eccentricity, obliquity and precession redistribute insolation.

Tens/hundreds of thousands of years; not the rapid modern warming cause.

Life and geology

Photosynthesis, oxygen accumulation, mineral oxidation and **ozone** co-evolved.

Anthropocene is not a formally adopted geological epoch.

AHL: Test an albedo mechanism

Design

Equal area, radiation input, initial temperature and position controls.

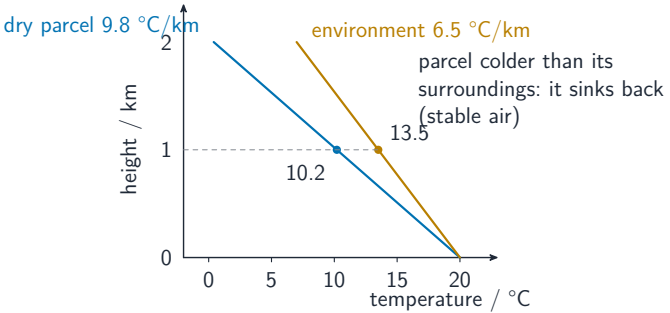
Replicate independent samples and measure reflected/incoming radiation.

Limits

Heating also depends on conductivity and emissivity.

A lamp model omits clouds, oceans, atmospheric transport and real solar spectrum.

Is the air stable?



The parcel is colder, so it sinks back: stable

AHL: Models and independent evaluation

Observations and physics

Stations, satellites, radar and calibrated proxies have distinct uncertainties.

Models represent conservation, radiation and interacting Earth systems.

Hindcasting

Run through historical conditions and compare with sufficiently independent observations.

Past agreement supports confidence but does not prove every future regional result.

AHL: Conditional scenarios

Five illustrative AR6 pathways

SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5.

Suffixes indicate approximate 2100 forcing, not probabilities or warming degrees.

Uncertainty

Internal variability, observations, model structure and human choices.

A projection range is conditional information, not a claim that nothing is known.

AHL: Tipping elements and cascades

Mechanisms

Ice-sheet elevation/flow; freshwater and Atlantic overturning.

Amazon forest–fire–rainfall interactions; local coral state shifts.

Interactions

One change can alter another component's risk.

Timescales, thresholds and amplifying/damping interactions remain uncertain.

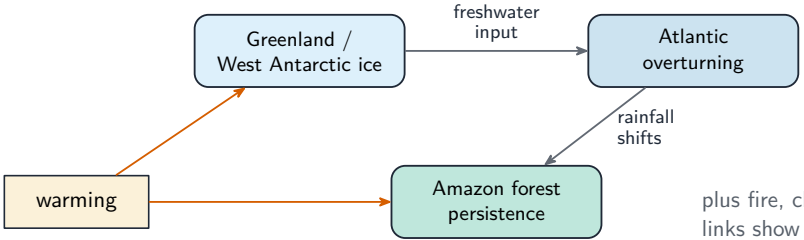
AHL: Country accounting

1. **Invented A.** 400 million tonnes CO_2/year $\div$ 40 million people $=$ 10 tonnes/person/year.
2. **Invented B.** 600 million $\div$ 200 million $=$ 3 tonnes/person/year.
3. **Compare.** B has greater total emissions; A has greater per-person emissions.

Decision

GCB 2024: cumulative fossil CO_2 1850–2023 differs from recent annual rankings; neither measure alone decides justice.

Linked tipping elements



plus fire, clearance, rainfall change;
links show possible influence,
not certain cascades

The links are possible, not certain

Cumulative or annual emissions?

share of cumulative fossil CO_2, 1850–2023



recent **annual** fossil emissions: China's are larger
dated fossil-carbon comparisons only: not all gases, land use, trade or capacity
(Global Carbon Budget 2024)

The two measures support different claims about responsibility

AHL: Policy categories interact

Examples

Economic: **carbon tax**/trading/subsidy.
Legislative: efficiency standards.

Industry: methane leak control, electrification and material efficiency.

Assess outcomes

Law can create a market; incentives can support industrial change.

Check additionality, rebound, monitoring, distribution and enforcement.

AHL: Capture fraction is not net reduction

1. **Invented boundary.** Process CO_2=100; captured=90; extra upstream/energy emissions=15.
2. **Residual.** (100−90)+15=25 units, if captured carbon is durably stored.
3. **Real context.** Brevik 2025 announcement: first 1000 tonnes captured during ramp-up; design 400000 tonnes/year.

Decision

A design capacity is not an observed annual total; point-source capture is not automatically removal.

AHL: Science, negotiation and delivery

Different roles

IPCC assesses evidence; UNFCCC COPs negotiate decisions.

Governments and other actors implement through domestic institutions.

COP30, Belém 2025

Latest completed COP as of October 2026.

Called for efforts to triple **adaptation** finance by 2035; delivery needs separate evidence.

AHL: Shared benefits and governance

Cooperation barriers

Free-riding, unequal capacity, finance, infrastructure and short horizons.

Transparency, reliable support and just-transition measures change incentives.

Intervention choices

CDR needs a negative net balance and durable storage.

Solar radiation modification raises regional and termination risks; does not remove ocean CO_2.

AHL: Perspectives and participation

Actors

Government infrastructure/laws; industry processes; NGO scrutiny.

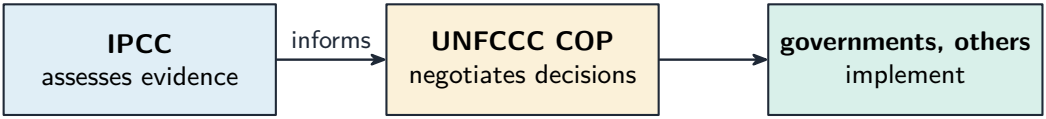
Personal demand and political participation within structural constraints.

Evidence and values

Trusted education/media/community can help; misinformation and affordability impede.

Neutral voluntary surveys; do not stereotype groups or equate intention with behaviour.

Who does what in climate policy



the IPCC sets no national targets and enforces no law

> Governments and others implement them

Removing carbon or reflecting sunlight

carbon dioxide removal

lowers atmospheric CO_2 if the full net balance is negative and storage lasts
can reduce the CO_2 that acidifies oceans

solar radiation modification

alters the energy balance only
CO_2 and ocean acidification remain
risks: regional rain, unequal effects, termination shock, who decides

It brings regional and governance risks

AHL: Explain a catalytic cycle

1. **Formation.** $O_2 + UV \rightarrow 2O$; $O + O_2 + M \rightarrow O_3 + M$. M carries away energy.
2. **Catalytic reactions.** $Cl + O_3 \rightarrow ClO + O_2$; $ClO + O \rightarrow Cl + O_2$.
3. **Cancel intermediates.** Net $O_3 + O \rightarrow 2O_2$; chlorine is regenerated.

Decision

Polar cloud activation and spring ClO-dimer chemistry require more than this simplified atomic-oxygen cycle.

AHL: Cooling choices link two problems

Direct and indirect effects

Refrigerant leakage versus electricity-related emissions.

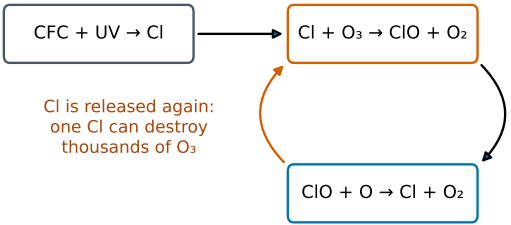
CFC/HCFC **ozone** effects; HFC warming varies; fluorine is not equivalent to catalytic chlorine.

Alternatives and access

Shading, insulation, greening, efficient equipment and cleaner power.

Assess low-GWP alternatives, safe servicing, recovery, affordability and heat protection.

How chlorine destroys ozone



the Montreal Protocol phased out CFCs; the ozone layer is slowly recovering

One atom can destroy thousands of **ozone** molecules

Exam tips

Quantities

Station/global; annual/long-term; CO_2/carbon; avoided/removal.

State period, units, boundary and uncertainty.

Evaluate

Trace the mechanism, not only the policy name.

Distinguish agreement, pledge, delivered funding and measured outcome.

Check yourself

Your turn

A surface receives 340 $\mathrm{W/m^2}$ with albedo 0.30. How much is absorbed in the stated solar-only model?

A. 238 $\mathrm{W/m^2}$.
B. 102 $\mathrm{W/m^2}$.
C. 340 $\mathrm{W/m^2}$.