
ECON1922 spring 2025
University of Oslo
SOLUTION

Instructions:

- (i) All problems should be solved. Weights are reported in brackets.
- (ii) Each exercise indicates how the question should be answered, whether we expect you to explain in words and/or provide a graphical illustration.
- (iii) Restrict your answer to what the exercise asks for. Non-relevant information is given no credit. Full credit will only be given to figures and graphs that are fully explained, accurately presented, and properly labeled on both axes.

This exam consists of 4 main questions.

The weight of each question is indicated, and the maximum is 100 points.

Question 1. The target (25 points)

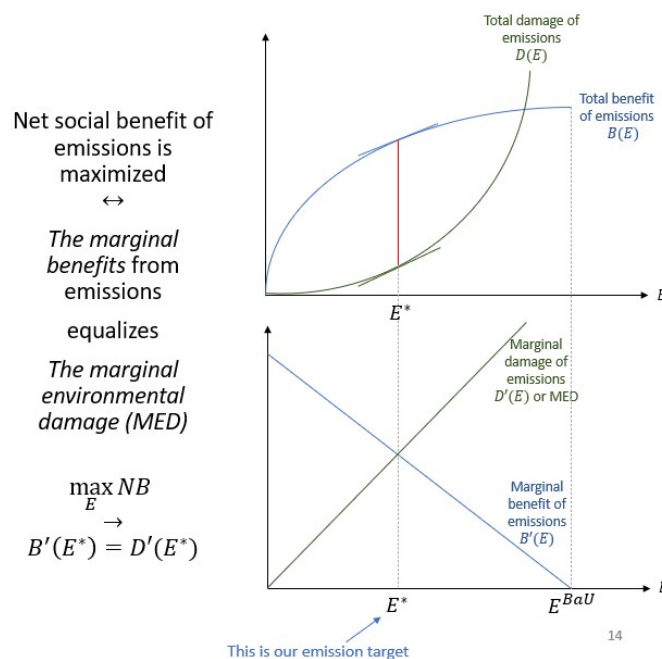


Figure I: Solution to question 1 (a), (b) and (c). Source: Lecture 3

(a) (5 points - figure)

Draw a diagram with emissions E on the horizontal axis. Illustrate the marginal benefit of emissions and the marginal damage from emissions. Explain the economic reasoning behind the shape and slope of each curve.

Solution key:

This is a core diagram in environmental economics (see Smith 2011, p. 21; and Lecture 3). An example is given in the bottom panel in Figure I.

- The marginal benefit of emissions, $B'(E)$ (or MBE), is downward-sloping. The first units of emissions are the most valuable, and the added value from additional emissions (e.g., through cheaper production or increased output) decreases as emission levels rise. In other words, it reflects the avoided cost of abatement — i.e., the value to firms or society of being allowed to emit one more unit. Some students might draw the MAC curve instead of the MBE, which is acceptable if they also explain the relationship between abatement and the benefits of emissions, since the exercise explicitly asks for the MBE.
- The marginal environmental damage $D'(E)$ (or MDE) is upward-sloping. It represents the additional environmental harm or cost to society from one more

unit of emissions. It typically increases with E because damage accumulates or worsens as pollution levels rise (e.g., ecosystem thresholds, health effects).

(b) **(5 points – figure and written answer)**

Using your diagram from (a), mark the emission level in an unregulated economy, and briefly explain what this level indicates using economic reasoning.

Solution key:

E^{BaU} is where marginal benefit = 0. This corresponds to the maximized benefit of emissions. See the bottom panel in Figure I.

(c) **(5 points - figure and written answer)**

Using your diagram from (a), mark the socially optimal level of emissions, and briefly explain what this level indicates using economic reasoning.

Solution key: The efficient level of emissions, denoted E^* , is determined where the two curves intersect:

$$B'(E^*) = D'(E^*)$$

At this point, the total net benefit to society is maximized. Emitting more would cause damages to exceed benefits; emitting less would forgo beneficial economic activity. See the bottom panel in Figure I.

(d) **(5 points – figure and written answer)**

Using your diagram from (a), illustrate and explain how the optimal level of emissions is affected if new technology makes it less costly to reduce emissions.

Solution key:

A technology that makes it less costly to reduce emissions lowers the marginal cost of abatement. Since the marginal cost of abatement (MAC) is the mirror image of $B'(E)$, this effectively reduces the marginal benefit of emissions. With cheaper abatement technologies, fewer economic resources are needed to achieve the same level of emission reduction. As a result, emissions become less essential (or less economically justified), and the optimal level of emissions decreases. The task does not specify whether the marginal benefit of emissions (MBE) curve changes in slope or shifts position, so either interpretation — provided it is clearly argued — is acceptable. See Figure III for a suggested solution.

(e) **(5 points – figure and written answer)**

Using your diagram from (a), illustrate and explain how the optimal level of emissions is affected if changes in the environmental system increase the harm caused by emissions.

Solution key:

If emissions become more harmful due to changes in the environmental system, this means the marginal damage caused by each unit of emissions increases. In the figure, this corresponds to an upward shift in the marginal damage curve. As the environmental cost of emissions rises, the socially optimal level of emissions decreases. This is because the point where marginal benefit equals marginal damage now occurs at a lower level of emissions. Therefore, society has stronger reasons to reduce emissions further to account for the increased environmental harm. The task does not specify whether the marginal benefit of emissions (MBE) curve changes in slope or shifts position, so either interpretation — provided it is clearly argued — is acceptable. See Figure III for a suggested solution.

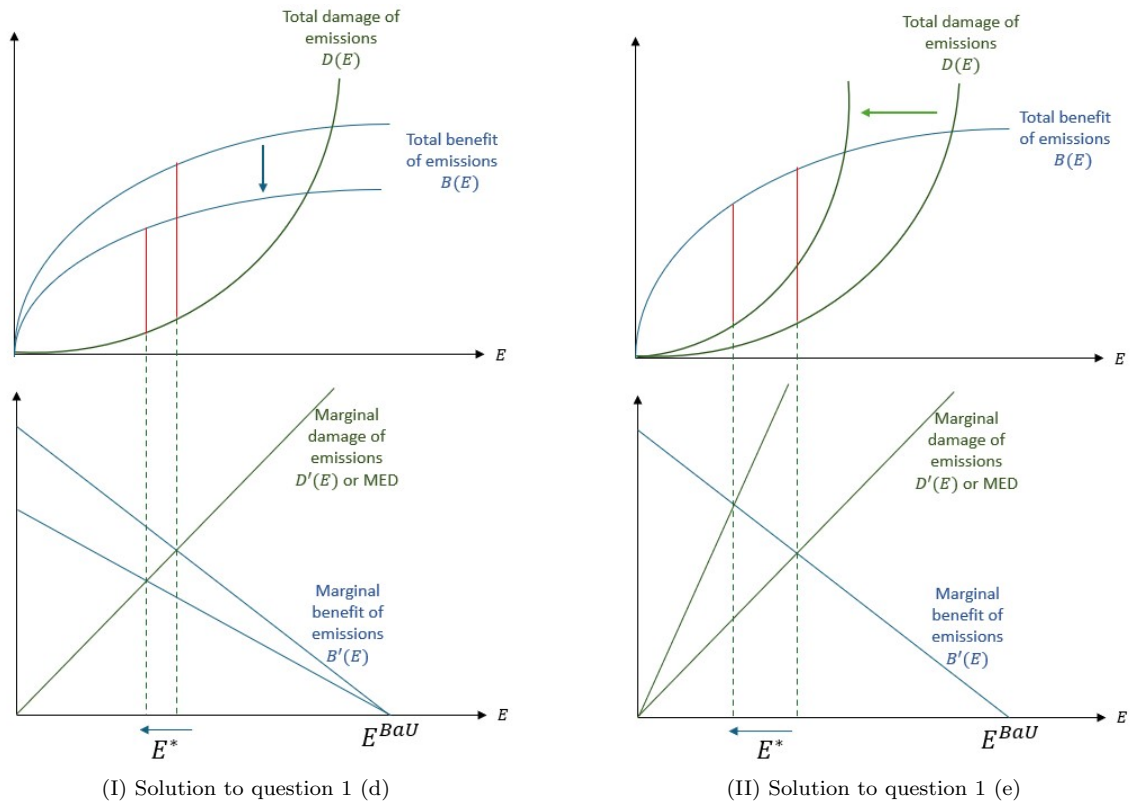


Figure II: The slope changes in the MBE or the MDE

Question 2. Abatement (35 points)

Marginal abatement cost (MAC) curves can take different shapes depending on the context. Figure III illustrates three different possible shapes of a MAC curve.

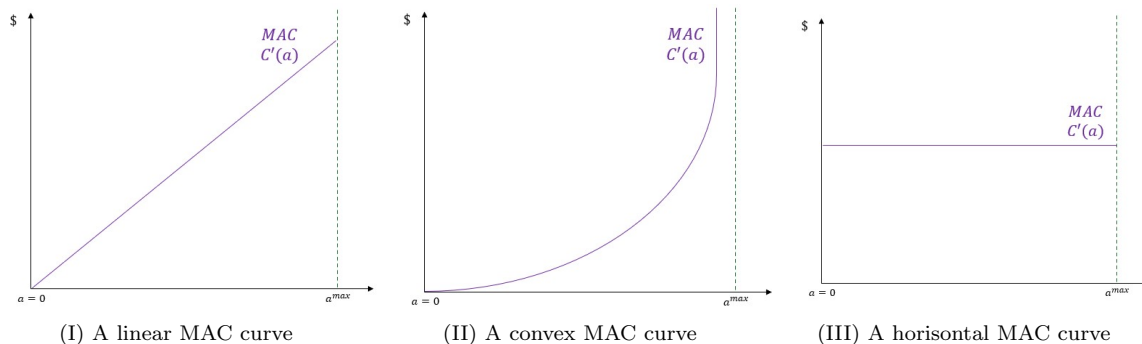


Figure III: Three different shapes of the MAC curve

(a) (10 points – written answer)

What is abatement? Explain the difference between a marginal abatement cost (MAC) curve that is linearly increasing, convex, or horizontal. How does the shape of the curve reflect the underlying cost structure of abatement efforts?

Solution key:

- **Abatement:** Emission reduction, measures in emission-units (quantity). $a = 0$ means 0% abatement and $a^{\max}$ means 100% abatement
- **Abatement costs:** These are opportunity costs — i.e., resources that must be redirected from other uses. Examples:
 - Installing end-of-pipe technologies (e.g., filters, scrubbers);
 - Switching to cleaner production processes or inputs;
 - Reducing output or changing behavior.
- **Marginal Abatement Cost (MAC):** The MAC curve shows the cost of reducing one additional unit of pollution (i.e., the marginal cost of abatement), measured in monetary terms. Its shape reflects how these costs evolve as more abatement is undertaken.
- **Linearly increasing MAC:** A linearly increasing MAC curve means marginal costs rise at a constant rate (the increase is constant). Each additional unit of abatement costs slightly more than the previous one. This assumes a steady increase in difficulty or expense.

- **Convex MAC:** A convex MAC curve means that the cost of additional abatement increases with the level of abatement already achieved (the increase is accelerating). Early reductions are relatively cheap, but further reductions become progressively more expensive. This is common when low-cost options are exhausted first and for those types of production or pollution where it is not possible, technically or economically, to reach 100% abatement (i.e., zero emissions) – the cost curve typically becomes very steep and never reaches $a^{\max}$.
- **Flat (horizontal) MAC:** A flat MAC curve at a high level means that the cost of reducing emissions is constant across all levels of abatement, regardless of how much has already been abated (it is not increasing). This might reflect a case where abatement technologies are costly, but the same for all abatement units, from the first to the last unit.

(b) (5 points - written answer)

Now, consider an industry consisting of two polluting firms, $i = A, B$, each with different abatement technologies. The two firms' MAC_i curves are illustrated in Figure IV. What is the total emissions in an industry consisting only of Firm A and Firm B. Which firm is the high cost abater? Explain why.

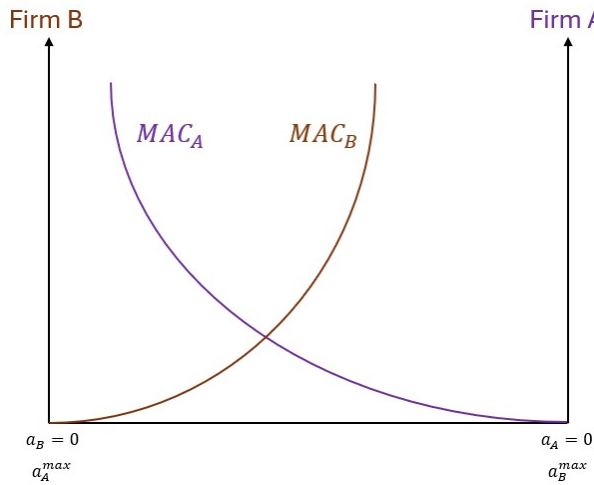


Figure IV: Convex Marginal abatement cost curves for Firms A and B

Solution key:

Emissions in the unregulated equilibrium is denoted by E^{BaU} and given where abatement equals zero $a = 0$ for all firms. Total emissions in the unregulated market is given by

$$E^{BaU} = E_A^{BaU} + E_B^{BaU}$$

Firm B is the high cost abater compared to Firm A in this industry, since the marginal

abatement cost (MAC) curve is steeper for B than A. For the same amount of abatement, the marginal costs are higher for firm B than firm A because they have different technologies and production processes.

(c) **(5 points - written answer)**

Explain what a command-and-control policy is, and provide examples.

Solution key: A command-and-control (CAC) policy refers to a regulatory approach where the government sets specific rules or limits that firms or individuals must follow to control environmental outcomes. These are often uniform standards, not tailored to firm-specific abatement costs. Examples are:

- *Technology standards: Require firms to use specific technologies or practices (e.g., scrubbers on smokestacks).*
- *Performance standards: Set limits on the amount of pollution a firm or facility can emit (e.g., emission caps).*

(d) **(5 points - written answer)**

Explain the least-cost theorem. What is the key efficiency criterion in the least-cost theorem when dealing with uniformly mixing pollutants?

Solution key:

- *The least-cost theorem states that to minimize total costs of achieving a given pollution reduction target, marginal abatement costs (MACs) should be equalized across all emitters: $MAC_1 = MAC_2 = \dots = MAC_n$.*
- *This result relies on the pollutant being uniformly mixing — meaning each unit of pollution has the same environmental effect regardless of source or location.*
- *This is important because firms differ in abatement costs. Equalizing MACs allows low-cost abaters to reduce more, and high-cost abaters less, while still achieving the target at the lowest possible total cost.*

(e) **(5 points - figure)**

Use Figure IV to draw an example of a command-and-control policy that violates the least-cost theorem. Mark in your figure how much each firm abates and their total abatement costs.

Solution key: See Figure V. The area under the MAC curve is the total abatement cost. The CC-policy here requires an equal emission quantity across firms, denoted by a Q in the figure. The least cost theorem is violated, as the MAC is different across firms for this type of policy.

(f) **(5 points - figure)**

Use Figure IV to draw an example of a uniform emissions tax t that satisfies the

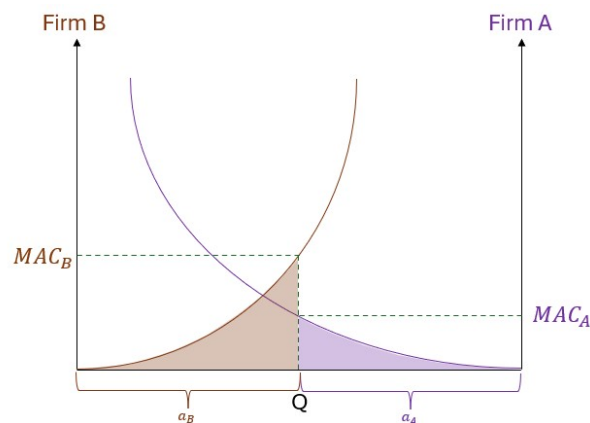


Figure V: Solution to Question 2 (f) command-and-control policy

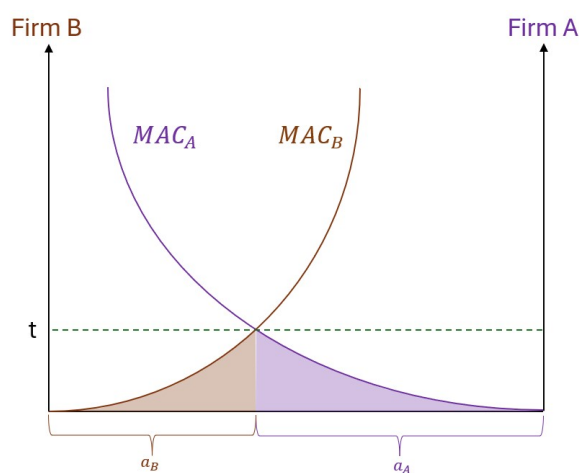


Figure VI: Solution to Question 2 (g) uniform tax

least-cost theorem. Mark in your figure how much each firm will abate and their total abatement costs.

Solution key: See Figure VI

- *The least cost theorem: To achieve a given environmental target (e.g., a certain level of pollution reduction), the total cost to society is minimized when marginal abatement costs are equalized across all polluters.*
- *Examples of economic incentive instruments: Emission taxes (Firms reduce until their marginal abatement cost equals the tax.) and Cap-and-trade systems (Firms trade permits until their marginal abatement costs are equalized.) Some firms can reduce emissions cheaply, others only at high cost. Instead of requiring everyone to reduce the same amount, incentive-based-instruments require everyone to reduce emissions until the cost of reducing one more unit is the same for all. This ensures the target is met at the lowest total cost to society (The least*

cost theorem).

Question 3. Global public goods (30 points)

Consider a strategic setting involving N countries, where each country i can choose between two actions: abate or not abate. The payoff structure for each strategy is illustrated in Figure VII. All countries are identical and face the same set of payoffs.

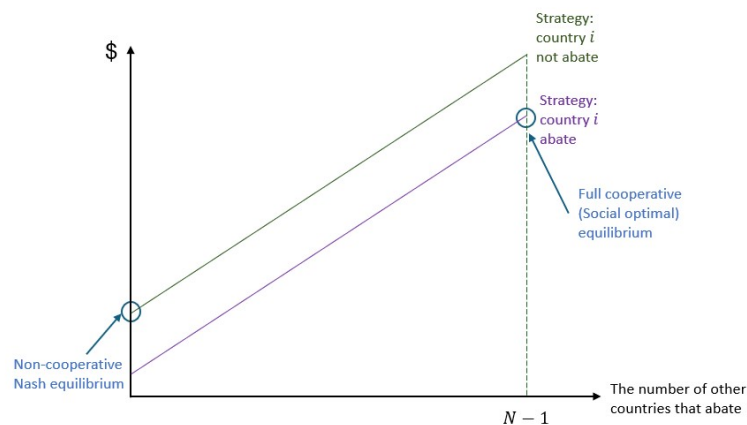


Figure VII: This figure depicts the payoff structure faced by country i in a symmetric two-strategy game involving N countries. The payoffs associated with each strategy increase linearly and remain parallel across the number of participating countries.

(a) **(5 points - figure and written answer)**

What is the non-cooperative solution to this game? Explain your reasoning and illustrate the equilibrium using the figure above.

Solution key:

See Figure VII. Since the payoff from not abating is always higher than the payoff from abating — regardless of what other countries do — “not abate” is a dominant strategy. Because all countries face the same payoff structure and incentives, each will choose not to abate in the non-cooperative equilibrium. This results in a Nash equilibrium where no country has an incentive to unilaterally change its strategy.

(b) **(5 points - figure and written answer)**

What is the full-cooperative solution to this game? Explain your reasoning and illustrate the equilibrium using the figure above.

Solution key:

See Figure VII. As more countries choose to abate (moving along the x -axis), the payoff to country i increases. This reflects the positive externalities of abatement, since the benefits of one country’s actions are shared globally. The slope of the payoff curves indicates the size of this externality. Because abatement is a global public good, all countries benefit from each other’s efforts. In the fully cooperative out-

come, all countries choose to abate, maximizing the total collective benefit and fully internalizing the externality.

(c) **(10 points - written answer)**

Explain why the abatement of CO₂ emissions can be considered a global public good. In your answer, include the definition of a public good and relate it to the characteristics of emission reductions.

Solution key:

- *Definition of a public good:*
 - *Non-rivalrous: One person's use does not reduce availability to others.*
 - *Non-excludable: It is difficult or impossible to prevent others from using it.*
 - *Examples: Abatement is an activity with public good characteristics, since it affects the environment, which is a public good. Other classical examples include clean air, national defense, and lighthouse services — but most credit is given to students who relate their examples to the course content.*
- *Why it leads to market failure:*
 - *Because the good is non-excludable, individuals have little incentive to pay for it.*
 - *This leads to the free rider problem, where people benefit without contributing.*
 - *As a result, the good is under-provided or not provided at all by the market.*
 - *This misallocation of resources is considered a market failure.*

Read Chapter 2 in Hanley et al. (2019).

(d) **(5 points - written answer)**

What is the *free rider problem* in relation to global public goods, and how does it apply to the game illustrated above? Explain the concept and its relevance in this strategic setting.

Solution key:

The free rider problem occurs when individuals or countries benefit from a good or service without contributing to its provision. In the context of global public goods — such as a stable climate and the abatement of Greenhouse Gas emissions — this means that each country has an incentive to let others bear the cost of reducing emissions while enjoying the shared benefits.

In the game illustrated above, abatement is a global public good, and the benefits of one country's actions are non-excludable and non-rivalrous. As shown in the

payoff structure, each country gains when others abate, but has a higher individual payoff by not abating itself. This leads to a dominant strategy of non-abatement, even though full cooperation would yield a better collective outcome. The result is a non-cooperative equilibrium with underprovision of the public good—a classic example of the free rider problem.

(e) (5 points - written answer)

Why can't countries be forced to coordinate on the fully cooperative outcome in international climate agreements? Explain the underlying reason.

Solution key:

Countries cannot be forced to choose the fully cooperative strategy in international climate agreements because there is no supranational government with the authority to regulate sovereign states. Each country retains its sovereignty, meaning that participation in international agreements is voluntary, and compliance is based on self-interest and trust rather than enforceable legal power.

Question 4. Economic growth and emissions (10 points)

In class we have discussed the correlation between growth in income and CO₂ emissions in a historical perspective. Figure VIII illustrates the development the last 70 years.

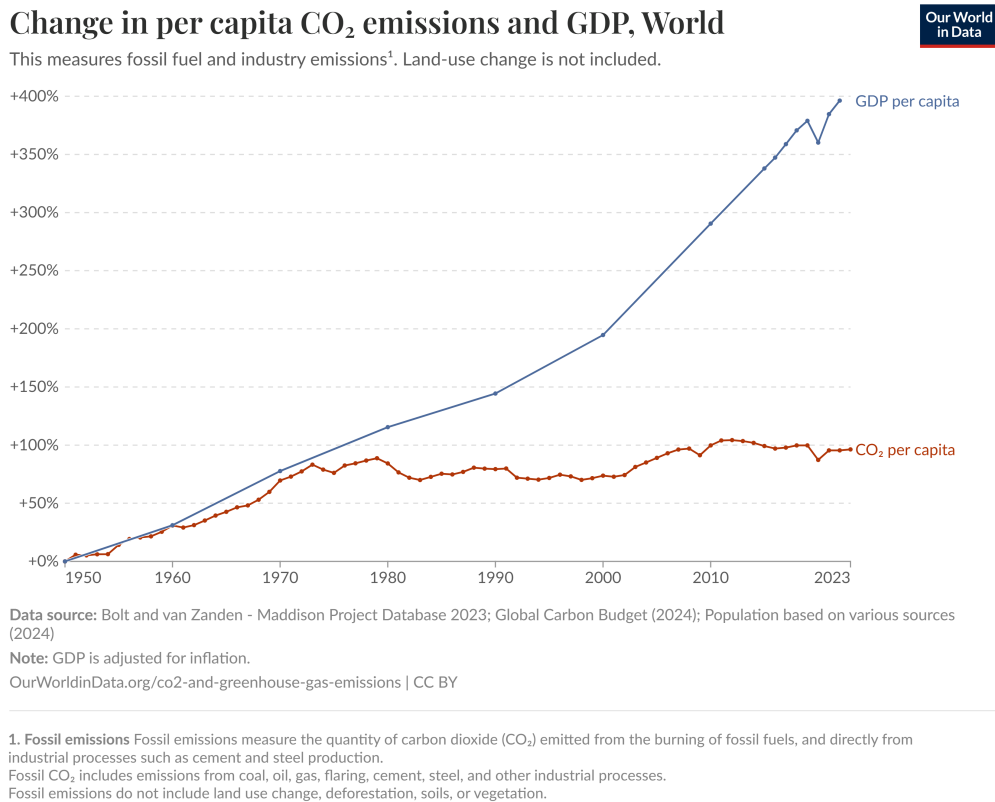


Figure VIII: Change in per capita CO₂ emissions and GDP in UK, Sweden, US and France. Source: Our World in data

(a) (5 points - written answer)

Help us interpret Figure VIII. What does it show, and what are the key takeaways?

Solution key:

This exercise assesses the student's ability to interpret and clearly explain a figure based on descriptive historical data.

- **Y-axis:** Percentage change relative to 1950 in (i) GDP per capita and (ii) CO₂ emissions per capita globally.
- **X-axis:** Time, spanning from 1950 to 2023.
- **Key observation:** GDP per capita has increased at an accelerating rate since 1950, reflecting economic growth. CO₂ emissions per capita followed a similar

upward trend until around 1970, after which emissions have remained relatively stable.

(b) (5 points - written answer)

Provide a brief interpretation of the concepts *GDP per capita* and *CO₂ emissions per capita*, explaining what each represents and why they are important indicators.

Solution key: .

- *GDP per capita refers to the total economic output (Gross Domestic Product) of a country or region divided by its population. Hence, market goods and services per person measured in \$. It is commonly used as an indicator of average income, living standards or level of economic development.*
- *CO₂ emissions per capita is total emissions produced within a country or globally, divided by the population. It reflects the average contribution of each person to CO₂ emissions, alternatively “emissions of an average person in the world”. In class we have discussed how GDP per capita can be thought of as an driver to CO₂ emissions per person.*