Modelling Non-renewable Energy Resources Hands-on Session for Beginners

21 Feb 2024, Wed

9 am NY | 2 pm London | 10 pm Beijing |

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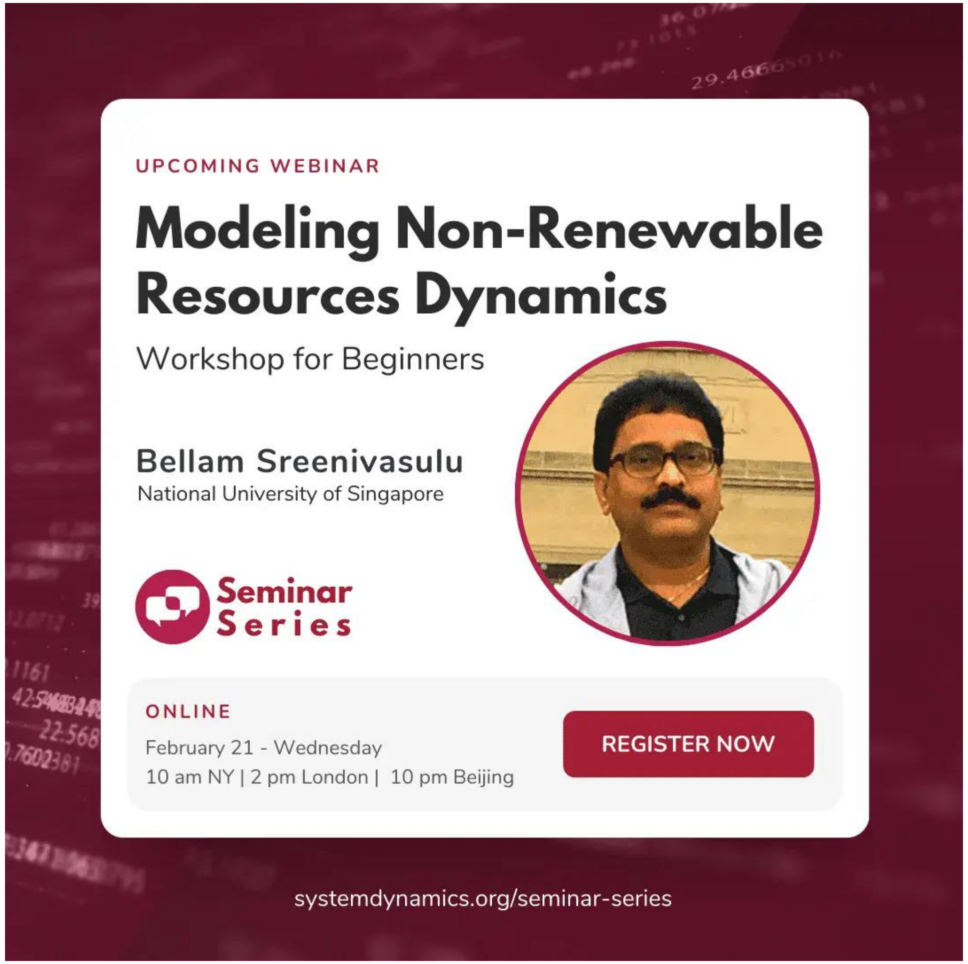
System Dynamics Society
Seminar Series



What is a 'System'?

- A system is a group of interacting, interconnected and interdependent elements/components that form a complex and unified whole.
- Systematic and coherent organization of interconnected parts in a pattern or structure generates a characteristic system's behaviour/function.

- Human body functions as 'whole system' through interconnected organs and their physiological functions

Elements/Parts of Systems

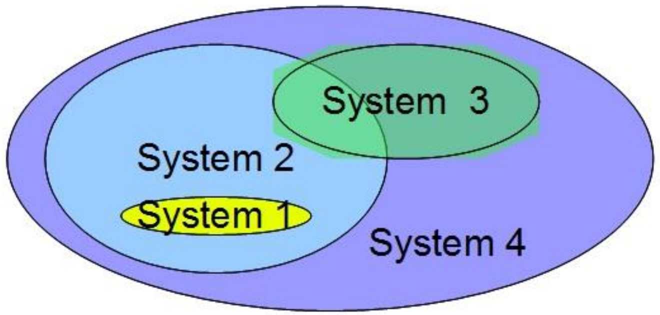
- Physical parts (we can see, touch etc.)
  - Parts of bicycle, human body organs, organization and people, etc.

- Intangible elements: invisible
  - Processes
  - Relationships
  - policies,
  - interpersonal relations
  - information flows, etc.
  - Internal states of mind
    - feelings, values, beliefs joy, respect, morale, motivation, happiness, etc.

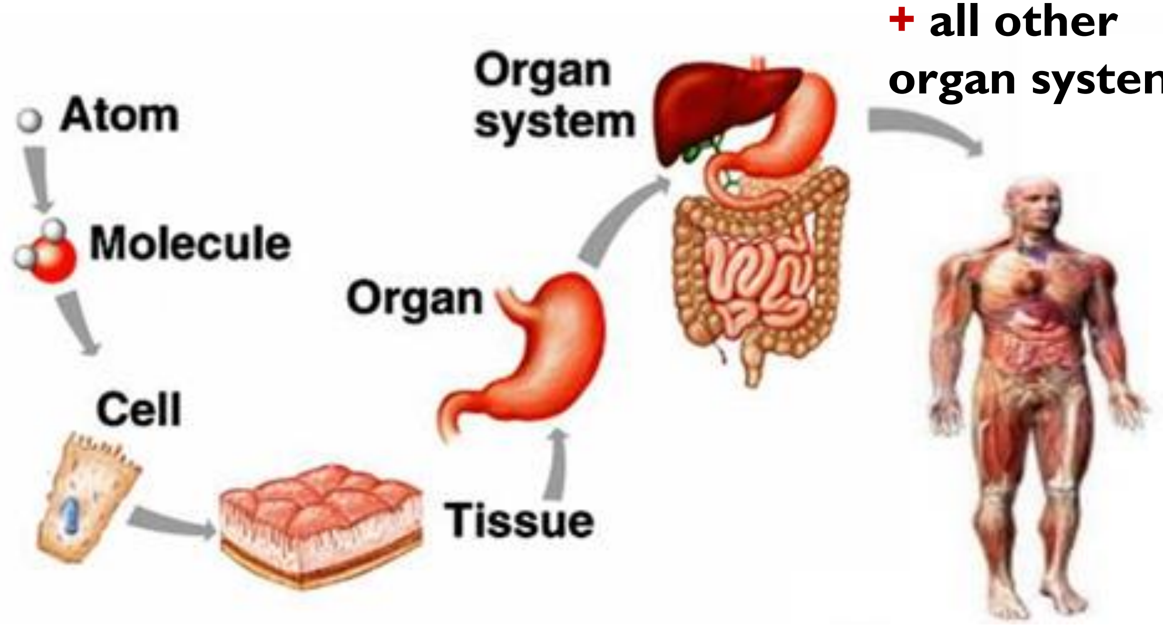
Systems and subsystems

Systems maintain boundaries

Big Systems: subsystems as interconnected elements



Small scale
low level



+ all other
organ systems

Large Scale
high level

Nature of Systems: Some important characteristics

Question

State whether the following is true or false? Why?

A system as whole = sum of its parts/components

True/False

Nature of Systems: Some important characteristics

System as an interconnected whole is much more than the sum/collection of its parts

A system as whole $\neq$ sum of its parts/components

E. g. Successful soccer team $\neq$ sum of the team members

Why?

- More is accomplished together than being apart
- Emerging aspects from the 'whole' are not seen in individual parts.
- System is not just sum/collection of parts. It is the interactions among the parts, over a time, of a system that generates system's emerging behaviour (which is beyond just a sum of the parts)

Is system's emerging behavior always a desired one?

System and its behavior

- Emerging behavior of a system is dynamic and complex
  - Emerging behavior of a System an emergent property normally appears at higher levels of scale as a result of interactions at lower levels

Thus,

A system can also be defined as**:**

a system is a set of interrelated components with emergent properties

Starting to ‘Thinking in Systems’

- What is your mental model of a system?
- Can you identify elements/parts? . . . and
- Do they affect each other? . . and
- Can you map circular cause and effects and identify the feedback?
- Do all the parts together produce an effect that is different from the effect of each part on its own? . . and perhaps
- Does the effect, the behavior over time, persist in a variety of circumstances?

System’s behavior can be determined by its ‘structure’

How to learn and develop systems thinking skills?

Tools of Systems Thinking

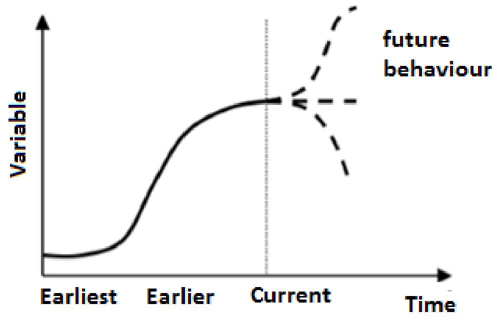
Tools of Systems Thinking

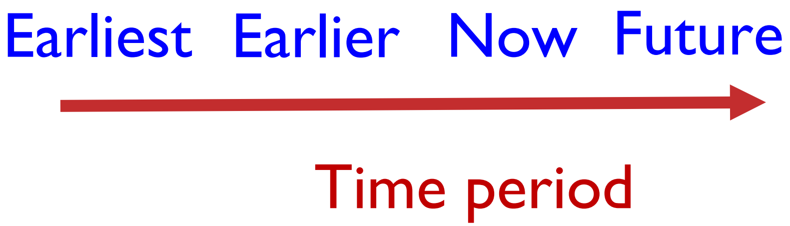
- Behaviour over Time Graphs (BOTGs)

A simple graph with horizontal (time) and vertical (changing factor) axes showing change over time.

Key Questions to think about 'system's behaviour'

- What changed?
- How did it change?
- Why did it change?
- Why is this change important?
- What will happen next?

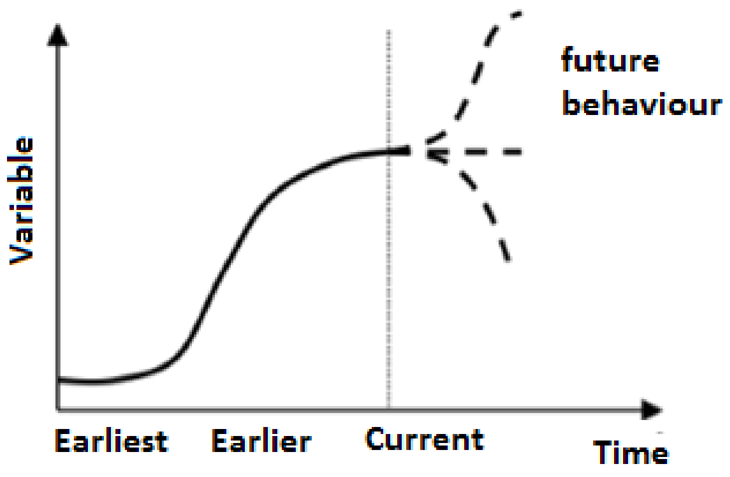


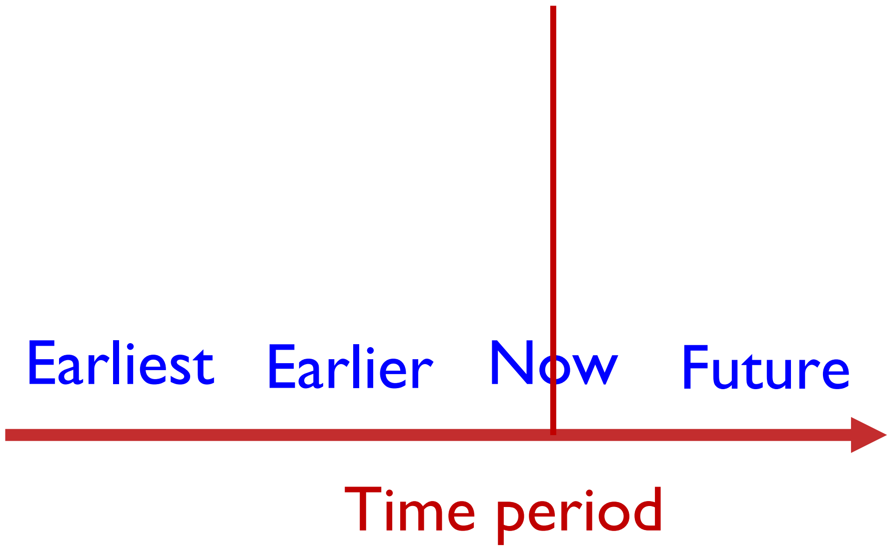


Tools of Systems Thinking

Drawing a Behaviour Over Time Graph (BOTG)

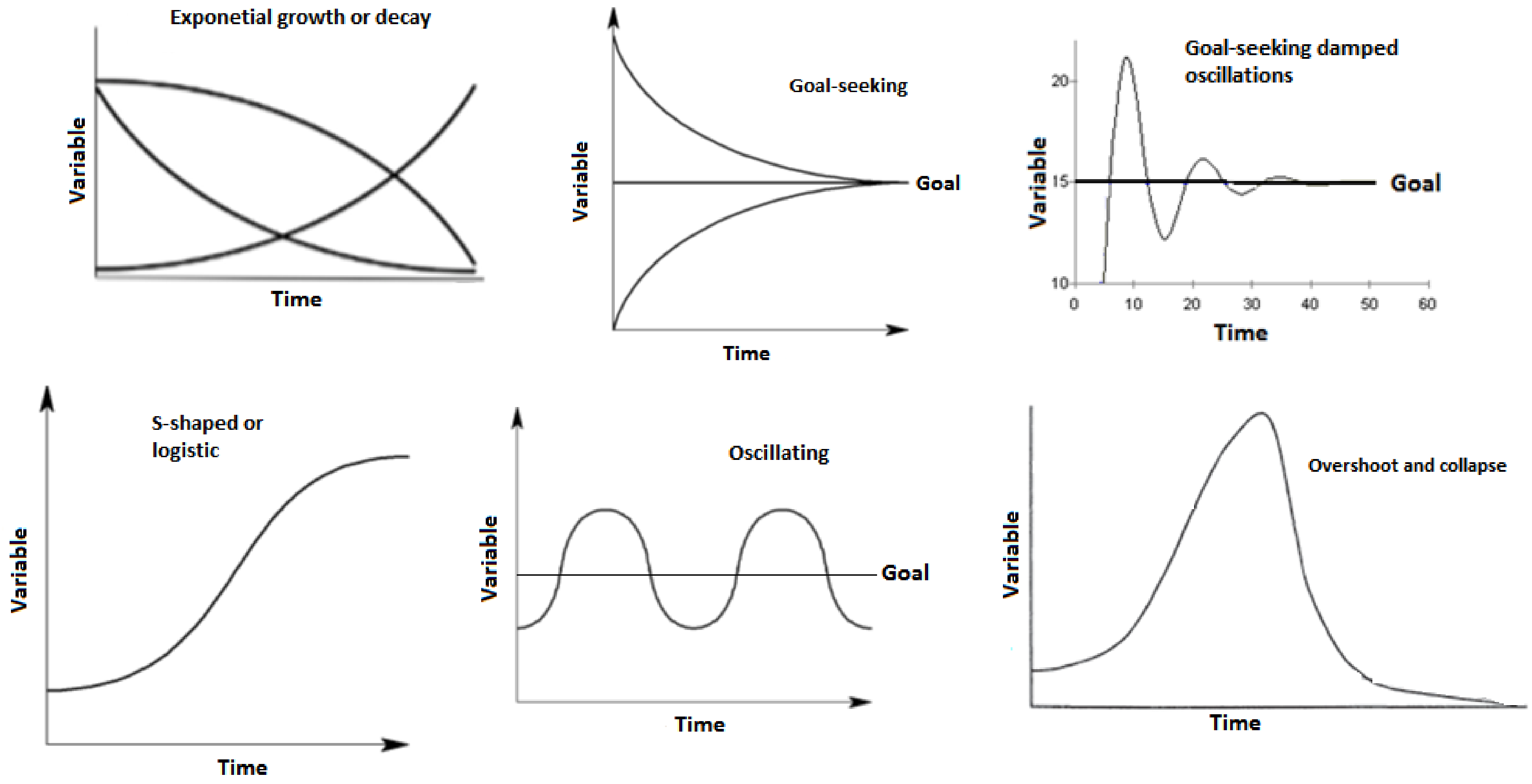
- Choose the time frame
- Sketch the historical with time on X-axis
- Draw vertical lines to indicate ‘current time’.
- Predict and sketch possible future projections.
- Label the vertical or y-axis for variable (using data)
    - Multiple variables can also be shown in single graph how they vary.





Patterns of Dynamic Behaviour

- Some common examples

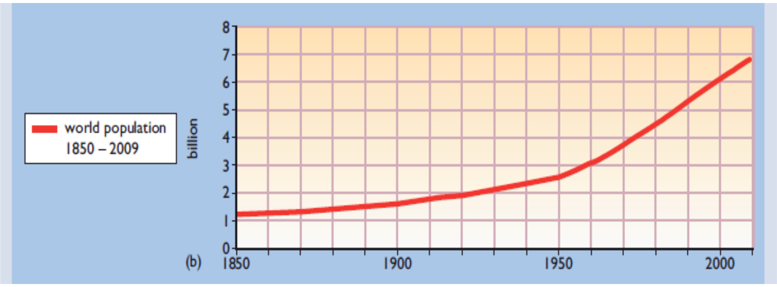


What causes/generates these dynamic behaviour patterns?

Interdependencies → System structures

Patterns of Dynamic Behaviour

- Some real world energy systems and behaviour patterns



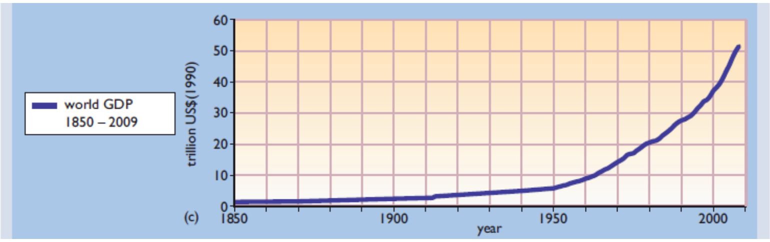


Figure 1-2. World energy consumption by region, 1990–2040 (quadrillion Btu)

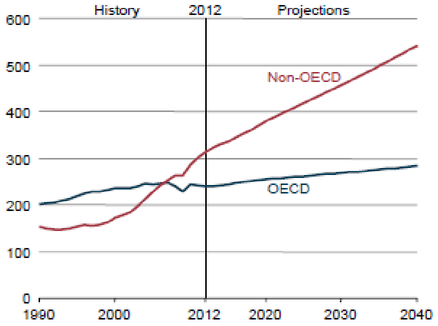
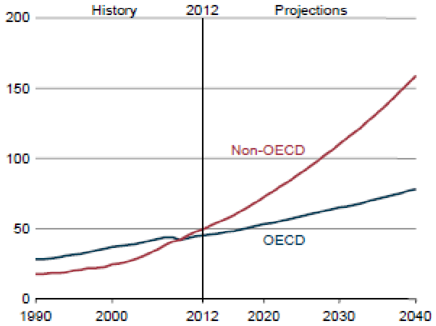
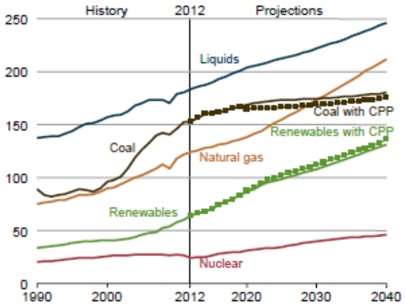


Figure 1-3. World total gross domestic product, 1990–2040 (trillion 2010 dollars)



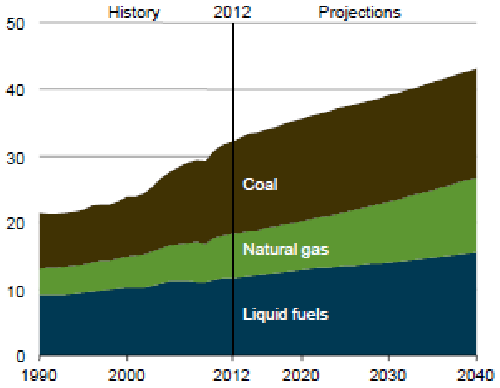
[10]For consistency, OECD includes all members of the Organization for Economic Cooperation and Development as of January 1, 2016, throughout every time series presented in this publication.

Figure 1-5. World energy consumption by energy source, 1990–2040 (quadrillion Btu)



Note: Dotted lines for coal and renewables show projected effects of the U.S. Clean Power Plan.

Figure ES-8. World energy-related carbon dioxide emissions by fuel type, 1990–2040 (billion metric tons)

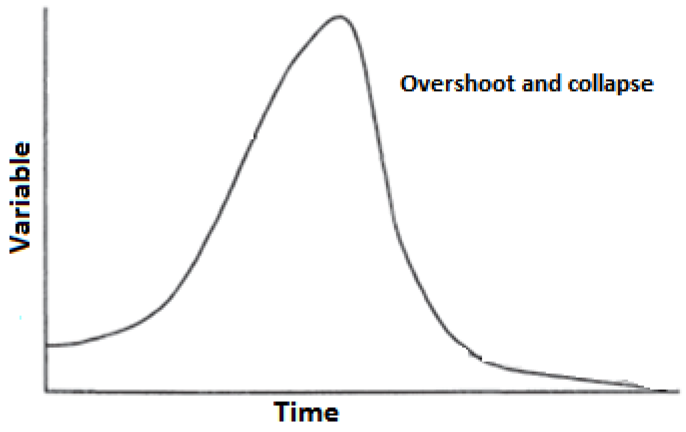


What causes/generates these dynamic behaviour patterns?

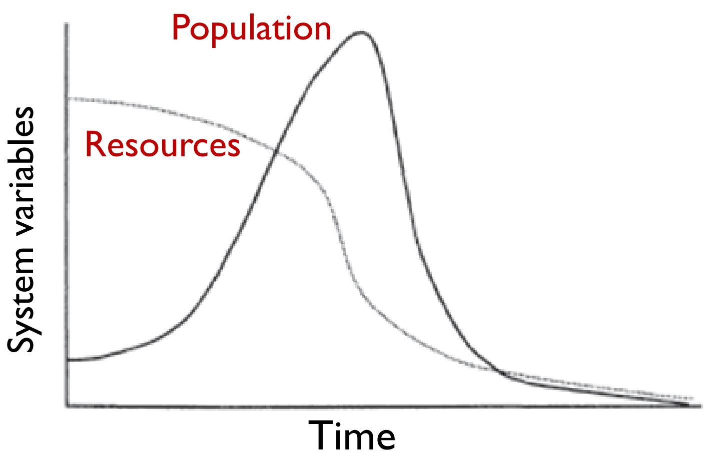
Interdependencies → system structures

Tools of Systems Thinking

- Overshoot and collapse



- Example



Initial exponential growth of the Population that continually consumes the resource and also depends on it for survival.
Reaches a peak and then collapse. Resource base continually decreases.
Both approach a steady state after the system collapses.

Example scenarios: Population growth with non-renewable resources; epidemiology

Tools of Systems Thinking
Causal Loop Diagrams (CLDs)

What causes/generates dynamic behaviour patterns?

Feedback through Interconnected interactions and Interdependencies → CLD

- In real world complex systems, problem symptoms and behaviours arise from the forces generated by a system's key causal loop structures/feedback loops.

- Mapping causal connections and construction of causal loop diagrams must be understood to solve the systemic problems

Causal Loop Diagrams (CLDs)

Diagramming causal connections

Positive (+) Link polarity

- If X and Y are two interdependent elements, then they are connected as: X ⟶ Y
  - An increase in 'X' causes an increase in 'Y' OR
  - A decrease in 'X' causes a decrease in 'Y'
- This type of effect is called +ve influence which means "a change in X causes Y to change in the same direction."
  - This is shown with a '+' sign near the arrow head of an arrow connecting X and Y
  - Here, the link polarity is '+ve'

As 'X' increases, 'Y' also increases

As 'X' decreases, 'Y' also decreases

Causal Loop Diagrams (CLDs)

Diagramming causal connections

Negative (-) Link polarity:

- -ve influence means "a change in X causes Y to change in the opposite direction." For example:
  - An increase in 'X' causes a decrease in 'Y' OR
  - A decrease in 'X' causes an increase in 'Y'

  This is shown with a '-' sign near the arrow head of an arrow connecting X and Y. Here, the link polarity is '-ve'

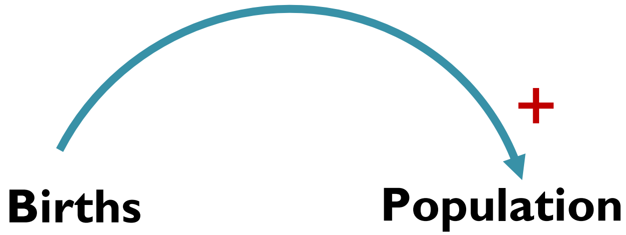
As 'X' increases, 'Y' decreases

As 'X' decreases, 'Y' increases

Causal Loop Diagrams (CLDs)

Diagramming causal connections

Some examples of positive (+) link polarity

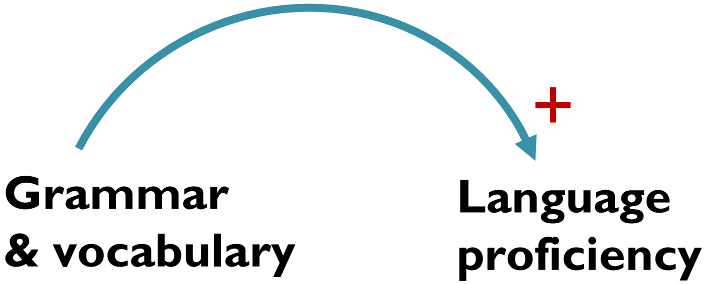


More births more population
(or) Lesser the birth rate lesser the population

More demand for workforce more jobs created.

or

As demand for workforce becomes less, jobs will also be less



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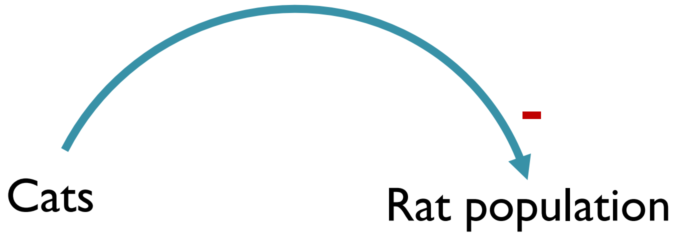
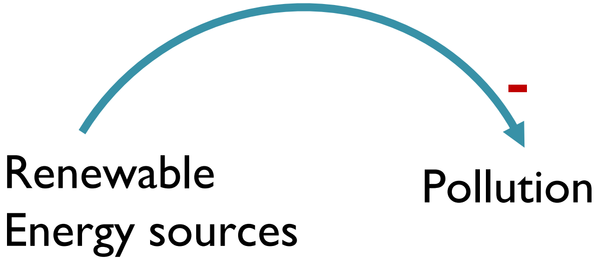
Causal Loop Diagrams (CLDs)

Diagramming causal connections

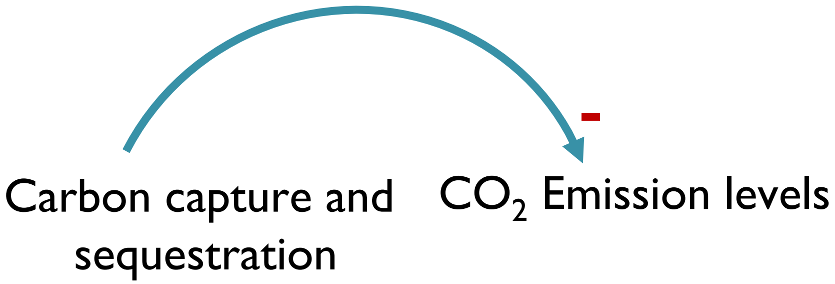
Some examples of negative (-) link polarity



More the cat population lesser will be rats (or) as the population of cats decreases, rats population will increase.



More renewable energy sources will result in less pollution. (or) Decreasing the renewable energy sources will increase pollution.



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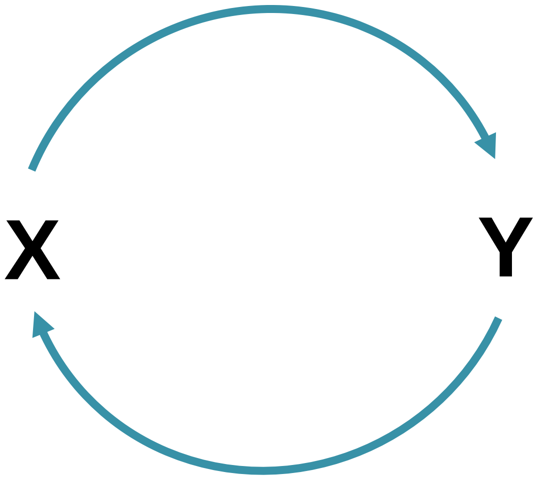
Causal Loop Diagrams (CLDs)

From causal links' to 'causal loops'

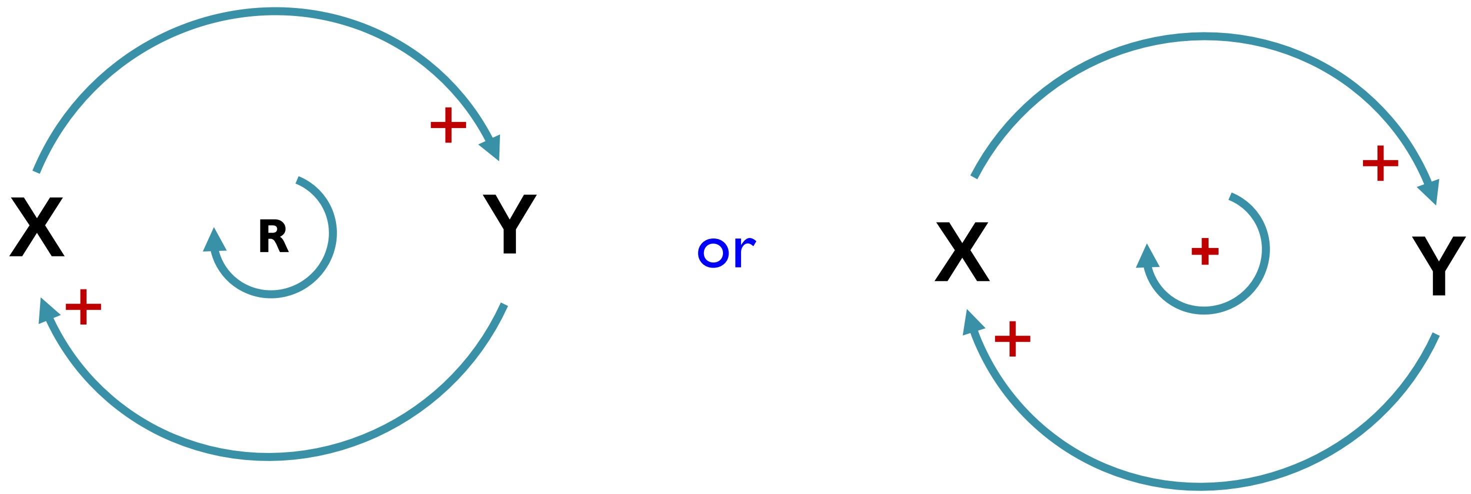
- identifying circular causality
  - Mutual causation between X and Y as a causal loop
  - "X" causes/affects "Y"; then does "Y" also cause/affect "X"? Does Y also act as 'cause'?
- Causal loops involve 'feedback'
  - What type of feedback and how does it affect the original change?



- Circular causal interaction between X and Y
- Individual Link polarities?
- Overall loop polarity?

Causal Loop Diagrams (CLDs)

- Positive or Reinforcing feedback loops
- Reinforcing Loop is labelled inside with one of the symbols:



As X increases, Y also increases and an increase in Y causes further increase in X

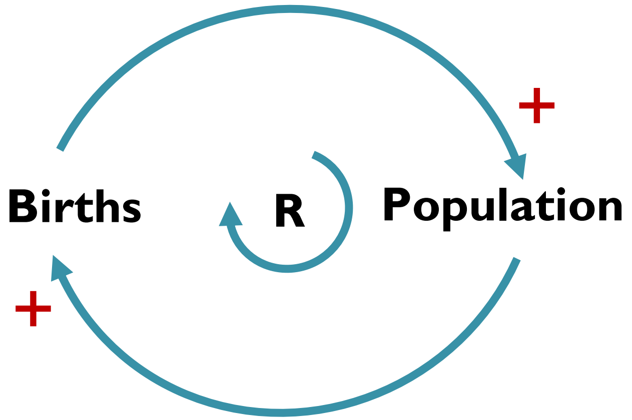
As X decreases , Y also decreases and a decrease in Y causes further decrease in X

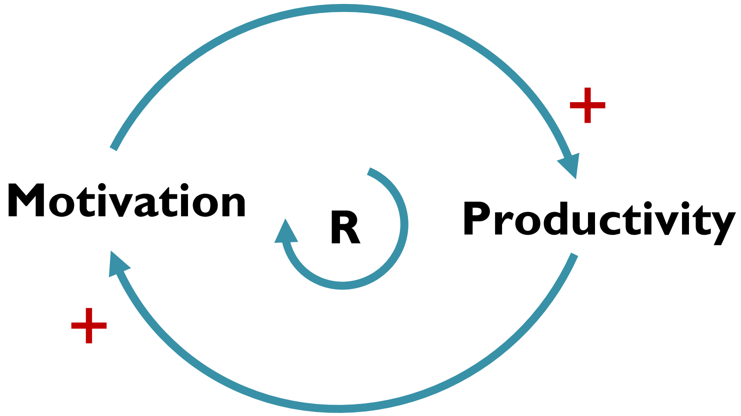
Product of the 'link polarities' in the loop is +ve

Causal Loop Diagrams (CLDs)

Constructing causal loops

From causal links to causal loops



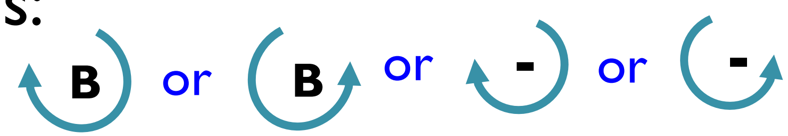


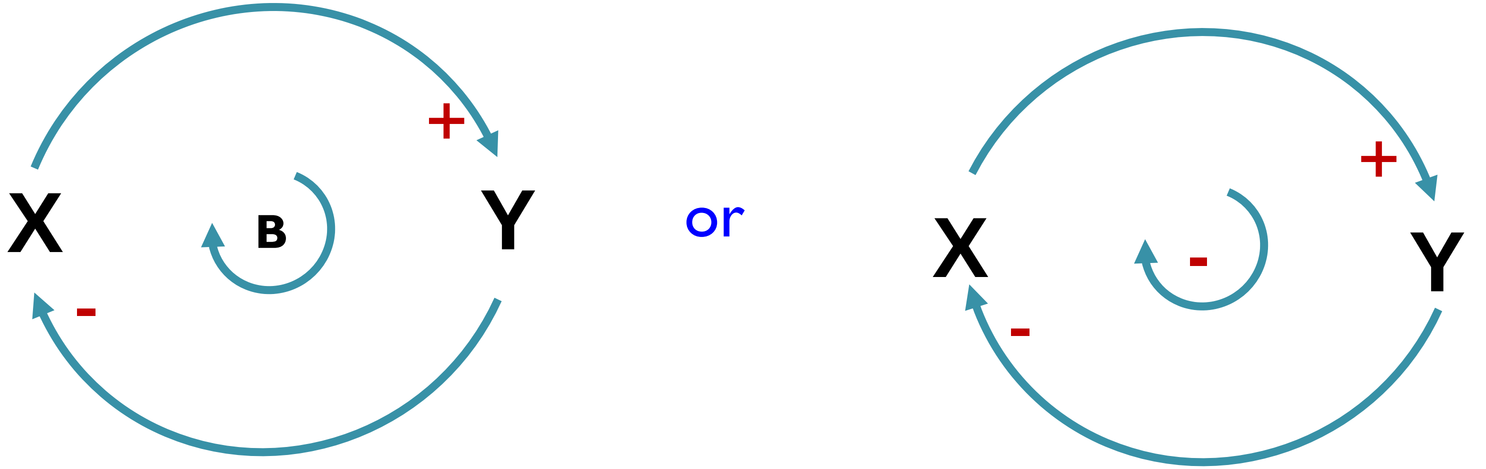
More births lead to more population and as population increases number of births will further increase.

As motivation levels increases, productivity will Increase. Increase in productivity will further increase motivation levels

Causal Loop Diagrams (CLDs)

- Negative or Balancing feedback loops
- Balancing feedback loop is labelled inside with one of the symbols:



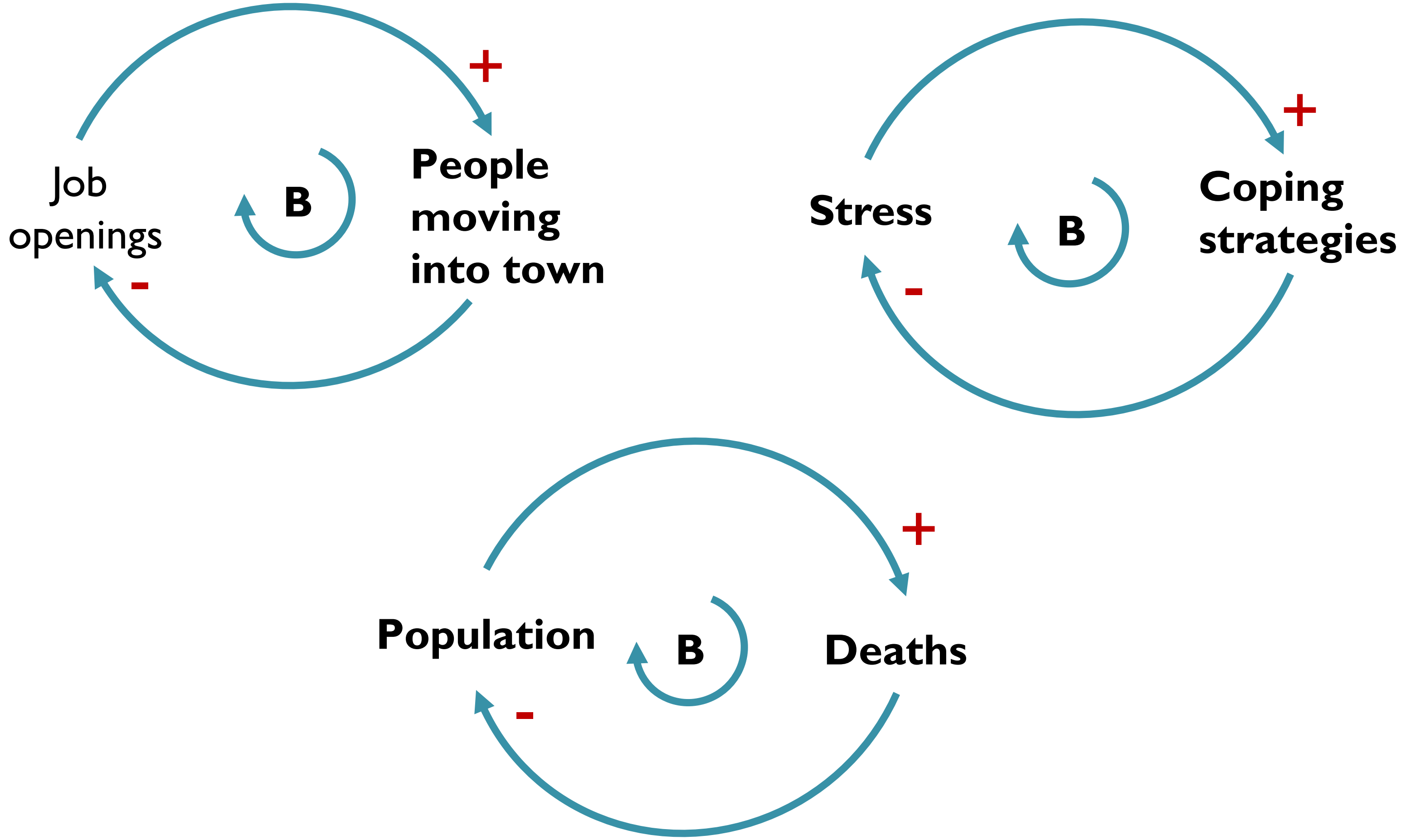


An increase in X causes an increase in Y and, this increase in Y causes a decrease in X than it were before (balancing effect)

Product of the link polarities in the loop is -ve

Causal Loop Diagrams (CLDs)

Balancing feedback loops: Examples



Introduction to ‘Stocks’ and ‘Flows’

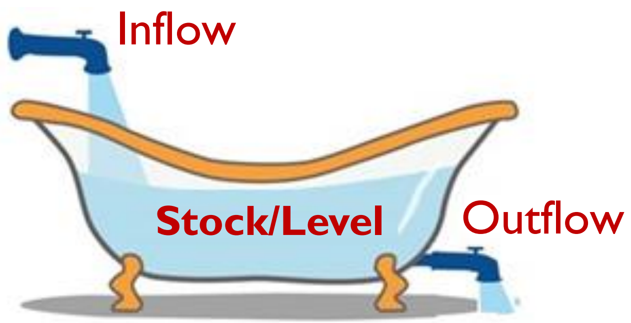
Stocks or Levels

A ‘stock’ or ‘level’ is an accumulation of ‘material’ or ‘quantity’ or ‘information’ over a period of time in a system

A ‘flow’ or ‘rate’ is either an input or an output for a stock

Flow actions or processes affect the amount of stocks

- Stocks increase by inflows
- Stocks decrease by outflows

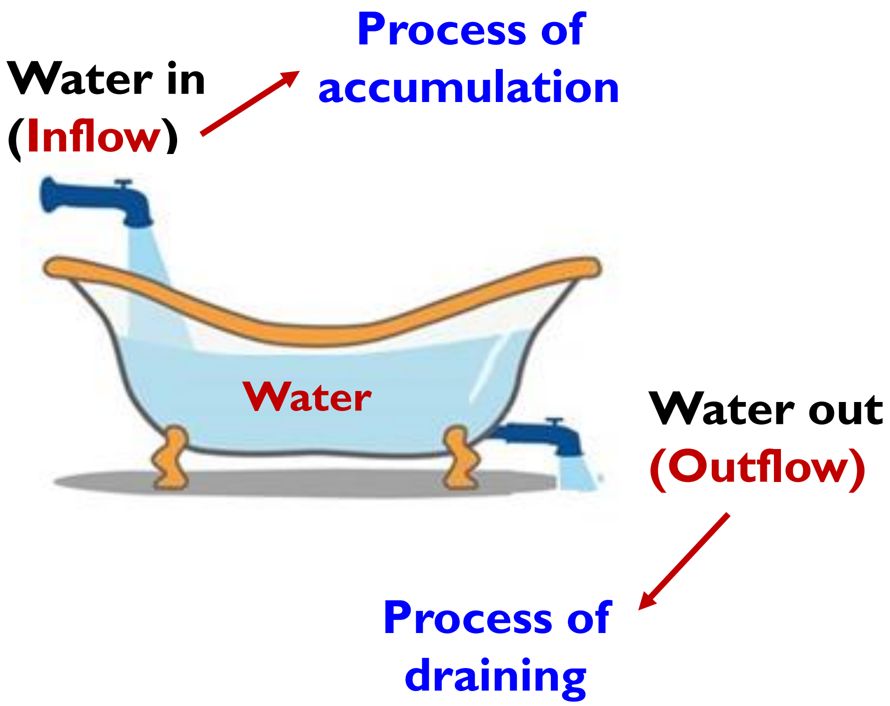


Introduction to ‘Stocks’ and ‘Flows’

‘Stock’ and ‘Flows’: Bathtub metaphor

- Accumulation and draining of Water.
  - How does water accumulate? How does water drain?
  - What would affect the amount/level of water in a bathtub?
  - How would you control the level of water?

Bathtub analogy for ‘stock and flows’



Introduction to 'Stocks' and 'Flows'

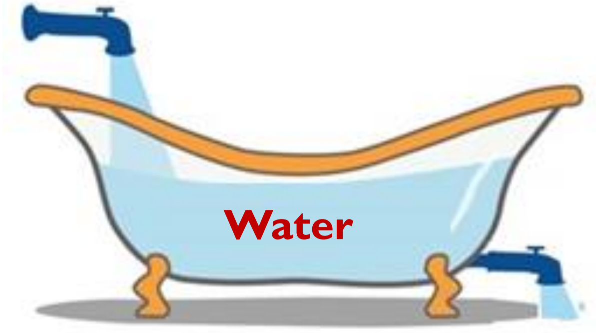
- Stocks or Levels are 'quantities' that accumulate in a system.
- Increase or decrease only by 'Flows'
- 'Units' must be correctly defined for both stocks and flows

Stock = Water
Quantity = Volume
Units = ml, litres, gallons etc.

Flows
(Water in and water out)
Inflow Rate and Outflow Rate

Units: Volume/time
ml/sec; litre/min, gallons/hour etc.

Water in (Inflow) → **Process of accumulation**



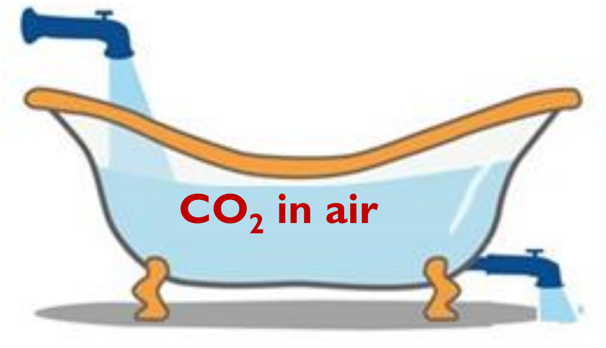
Water out (Outflow) → **Process of draining**

Introduction to 'Stocks' and 'Flows'

- Stocks or Levels are 'quantities' that accumulate in a system.
- Increase or decrease only by 'Flows'
- 'Units' must be correctly defined for both stocks and flows

Emissions
(Inflow)

Process of accumulation



Removals
(Outflow)

Process of draining

Stock = CO_2 in atmosphere
Quantity = Volume or weight
Units = ml, litres, parts per million, tons etc.

Flows
(**CO_2** in and **CO_2** out)
Emission Rate and Removal Rate

Units: Volume/time
ml/sec; litre/min, ppm/hour, ton/year etc.

Introduction to ‘Stocks’ and ‘Flows’

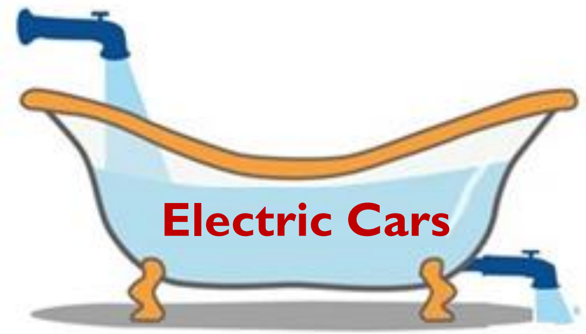
Energy production
(Inflow)

Energy consumption
(Outflow)

Stock = Energy
Units = kilojoules, megajoules, etc.

Flows: Inflow Rate and Outflow Rate
Rate of Production and Rate of consumption
Units: **energy/time**
kilojoules/hour; megajoules/hour, etc.

Electrification of conventional cars
(Inflow)



Degradation
(Outflow)

Stock = Electric Cars
Units = No. of Electric cars

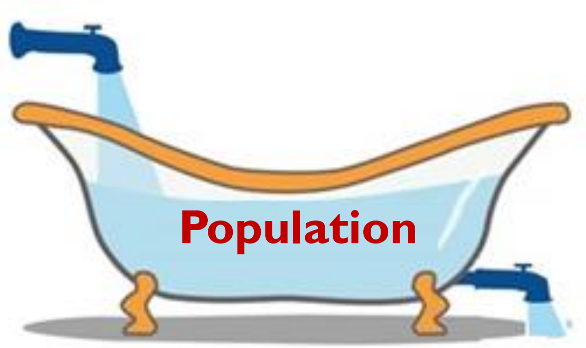
Flows: Inflow Rate and Outflow Rate
Electrification rate and Degradation rate
Units: **cars/time**
cars electrified/time; cars degrading/time

Introduction to 'Stocks' and 'Flows'

Oil extraction
(Inflow)

Oil exportation
(Outflow)

Births
(Inflow)



Deaths
(Outflow)

Stock = Oil
Units = gallons, barrels, etc.

Flows: Inflow Rate and Outflow Rate
Extraction rate and Exportation rate
Units: **gallons/time**
gallons/hour; barrels/day, etc.

Stock = Population
Units = people, rabbits, fishes, bacteria, mosquitos etc.

Flows: Inflow Rate and Outflow Rate
Rate of births and Rate of deaths
Units: **people/time**
People/month; babies/year; rabbits/month, etc.

Introduction to Stocks and Flows

Examples of 'Stocks'

- Money in bank account
- CO_2 in atmosphere
- Blood sugar
- Stored Energy in a capacitor
- Books in a library
- Charge in a battery
- Tress
- Landfills
- Fossil fuels
- Degree of belief
- Stockpiled vaccines
- Goods in a warehouse
- Confidence
- Happiness
- Beds in an emergency room
- Owned vehicles
- Anger

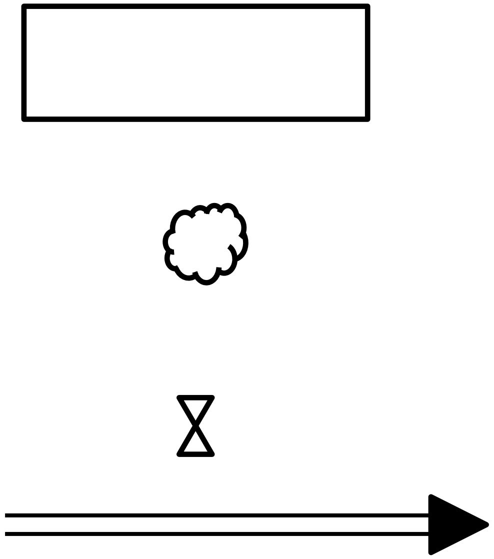
Introduction to 'Stocks' and 'Flows'

Examples of Flows (units/time)

- Inflow or outflow of a bathtub (e.g. litres/minute; gallons/hour etc.)
- Rate of incident cases (e.g. people/month)
- Rate of recovery
- Rate of mortality (e.g. people/year)
- Rate of births (e.g. babies/year)
- Rate of treatment (people/day)
- Rate of caloric consumption (kcal/day)
- Rate of pregnancies (pregnancies/month)
- Reactivation Rate (# of networks per unit time)
- Revenue ($/month)
- Spending rate ($/month)
- Power (Watts)
- Rate of energy expenditure
- Vehicle sales
- Vaccine sales
- Shipping rate of goods

Introduction to 'Stocks' and 'Flows'

Drawing Stock and Flow diagrams



Rectangular box: Stock or Level

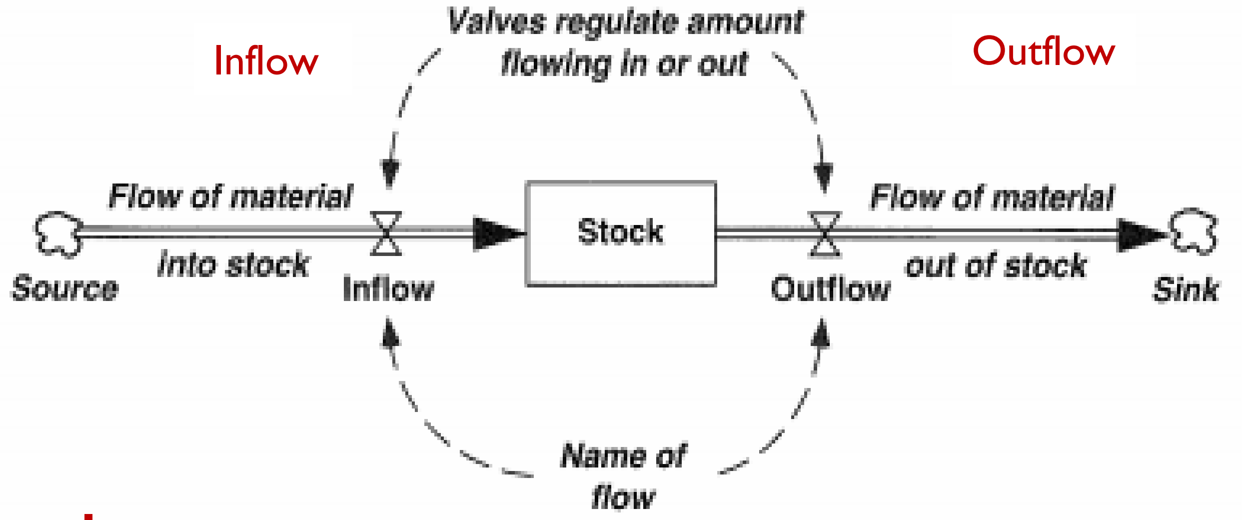
Cloud: source or sink (outside model boundary)

Valve/flow rate controller

Piped arrow to show: Flow direction

Introduction to ‘Stocks’ and ‘Flows’

Drawing Stock and Flow diagrams: General Structure



Example

Introduction to 'Stocks' and 'Flows'

Inflow	Stock	Outflow
Births/year	People in the city	Deaths/year
Litres/min	Water in bathtub	Litres/min
Happy events/day	Happiness	Unhappy events/day
pollutants/year	Pollution	Pollutant dissipation/year
Mails received/day	Mails in the inbox	Mails deleted/day
Cars entering	Cars parked	Cars leaving

Exercise

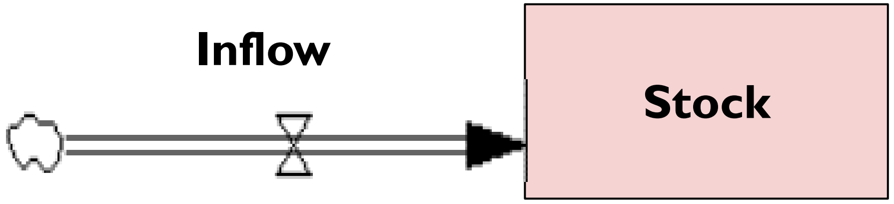
Identify the flows (with suitable units) for each type of stock given and fill in the blanks

____________	Electrical Energy	____________
____________	Natural Gas	____________
____________	Nuclear power plants	____________
____________	Wind Turbines	____________
____________	Biofuel reserves	____________
____________	Hybrid Vehicles	____________

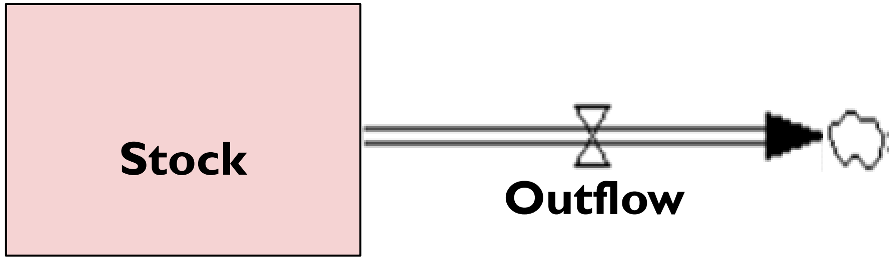
Introduction to ‘Stocks’ and ‘Flows’

Drawing Stock and Flow diagrams

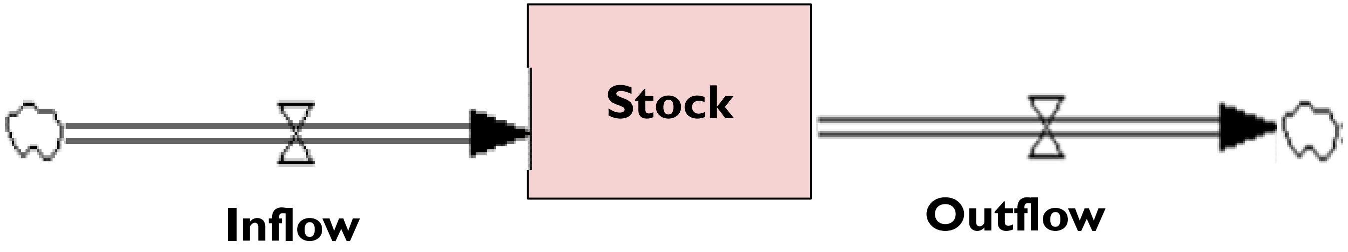
Influence of Flows on Stocks



Inflows increase the amount of Stock

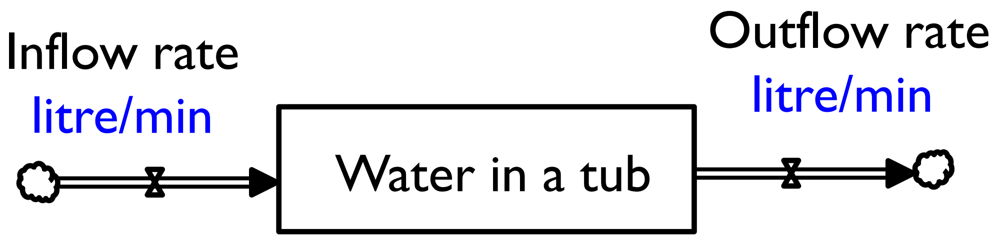


Outflows decrease the amount of Stock



Both inflow and outflow affect the amount of Stock

Introduction to 'Stocks' and 'Flows'



Amount of stock = inflows - outflows

What will happen to the water level or its volume?

Three cases:

- Case 1: Open the inlet fully and close the outlet fully
- Case 2: Close the inlet fully and open the outlet fully
- Case 3: Open inlet fully and open the outlet fully

Introduction to ‘Stocks’ and ‘Flows’

How do flows influence the amount of stocks?

Three cases and principles:

- Increase in stock’s level: As long as the sum of all inflows exceeds the sum of all outflows, the level of the stock will increase
  - Sum of inflows > sum of outflows; Stock level rises
- Decrease in stock’s level: As long as the sum of all outflows exceeds the sum of all inflows, the level of the stock will decrease
  - Sum of outflows > sum of inflows; Stock level falls
- Equilibrium (steady state) in stock’s level: If the sum of all outflows equals the sum of all inflows, the stock level will not change; then the stock is said to be at dynamic equilibrium (steady state)
  - Sum of inflows = sum of outflows; Stock in equilibrium

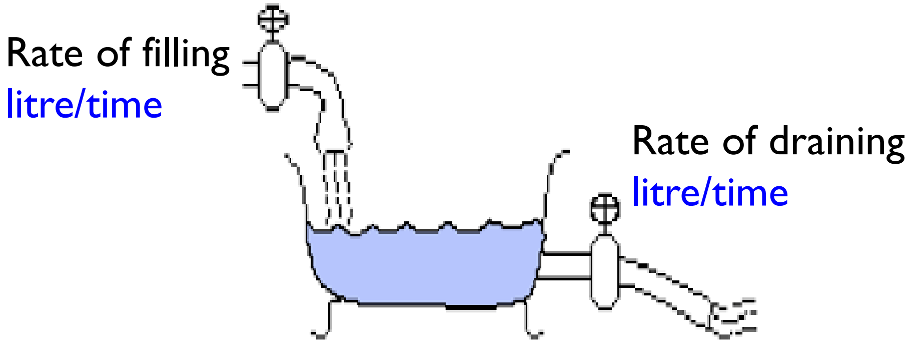
Introduction to ‘Stocks’ and ‘Flows’

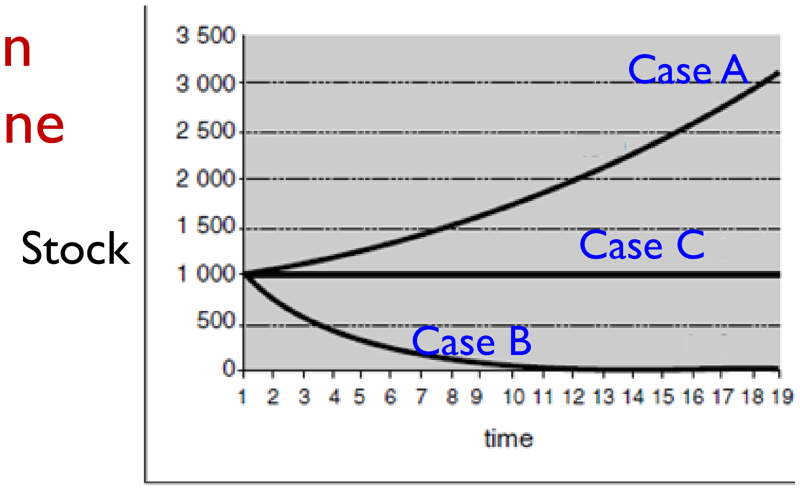
How do flows influence the amount of stocks?

Behavior of a stock: Three cases

- Case A: Sum of inflows > sum of outflows; Stock level rises
- Case B: Sum of outflows > sum of inflows; Stock level falls
- Case C: Sum of inflows = sum of outflows; Stock in dynamic equilibrium (steady state)

Observe the behavior of a stock in the given BOTG. Compare each line with the above cases.





BOTG of a stock

Stock and Flow Diagram/Model we work on