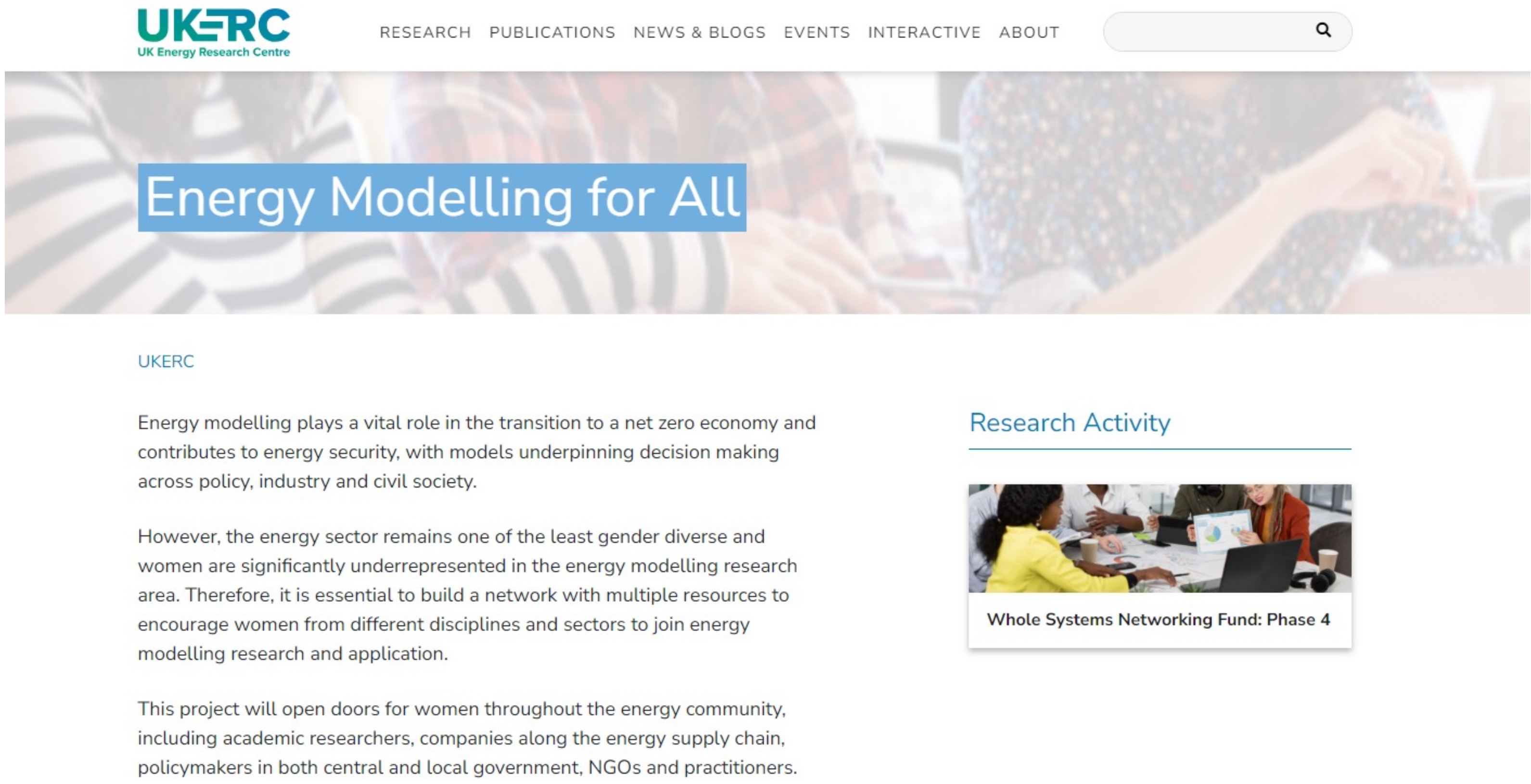
# ENERGY MODELLING FOR ALL

Dr Lirong Liu

Centre for Environment and Sustainability (CES)

University of Surrey



# Energy Modelling for All

UKERC

Energy modelling plays a vital role in the transition to a net zero economy and contributes to energy security, with models underpinning decision making across policy, industry and civil society.

However, the energy sector remains one of the least gender diverse and women are significantly underrepresented in the energy modelling research area. Therefore, it is essential to build a network with multiple resources to encourage women from different disciplines and sectors to join energy modelling research and application.

This project will open doors for women throughout the energy community, including academic researchers, companies along the energy supply chain, policymakers in both central and local government, NGOs and practitioners.

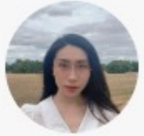
## Research Activity

**Whole Systems Networking Fund: Phase 4**

## Project team

**Lirong Liu**

**Nayanee Silva**



**Xinyao Liu**

# AIM

- Build a diverse network in energy modelling from different disciplines (e.g., social sciences, engineering, and economics) and different sectors (e.g., local authority, industry, and NGO).
- Establish a platform with open learning resources to provide a quick and fun way to begin to become familiar with the identified energy modelling and to enable the discussion among peer community.
- Host a series of events with hands-on learning, mentorship by energy modelling practitioners and supportive peer community to enable more women to use energy modelling to solve practical problems.

# WORK PACKAGES

**Month**

| **Start Date: 10/01/2022** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **WP1 Network establishment** | | | | | | | | | | | | |
| Task 1.1 Network building | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | | | | | | | |
| Task 1.2 Platform development | | | | | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | | |
| **WP2 Energy modelling learning resources development** | | | | | | | | | | | | |
| Task 2.1 Energy modelling scooping | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | | | | | | | |
| Task 2.2 Learning resources development | | | | | | 🟨 | 🟨 | 🟨 | 🟨 | 🟨 | | |
| **WP3 Network events and activities** | | | | | | | | | | | | |
| Task 3.1 Kick-off workshop | | | | | 🟩 | | | | | | | |
| Task 3.2 Summer Program | | | | | | | | | | | 🟩 | |
| Task 3.3 Long-term network workshop | | | | | | | | | | | | 🟩 |

# INTRODUCTIONS & WARM-UP ACTIVITY

**Nayanee Silva**

# GET TO KNOW YOU BINGO

# COFFEE BREAK

# GROUP DISCUSSION

## MODELLING PROBLEMS

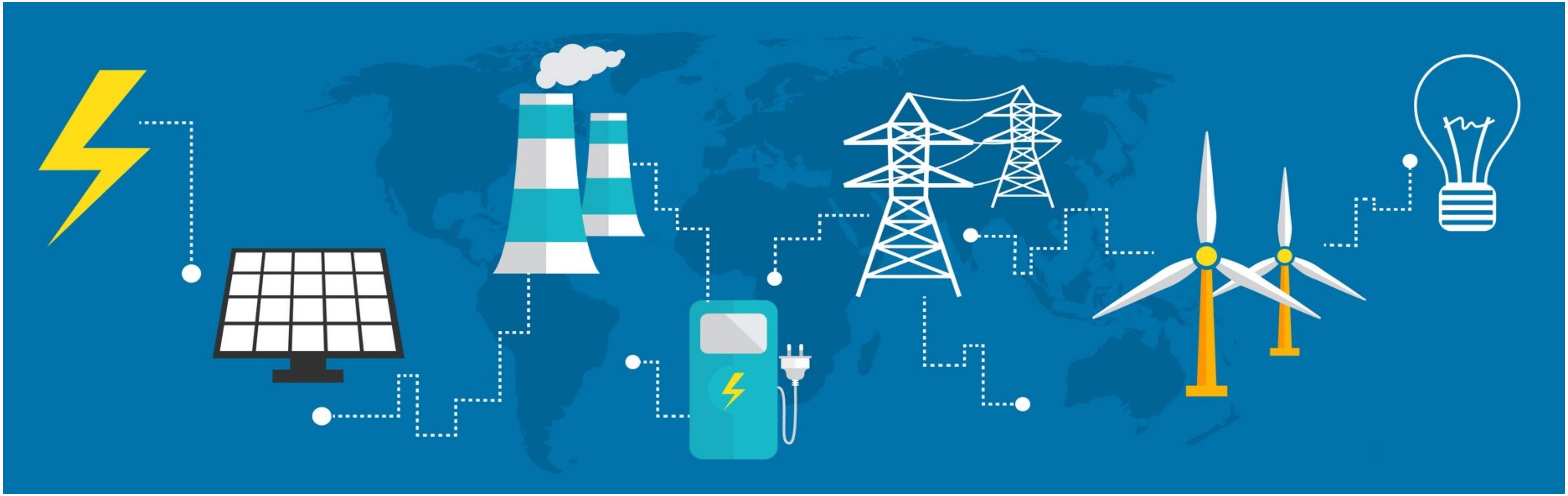
# LUNCH

# INTRODUCTION TO ENERGY MODELLING

Jiatai Wang, Centre for Environment and Sustainability (CES), University of Surrey

# CONTENT

- Background
- Methodology
- Application
- Takeaways

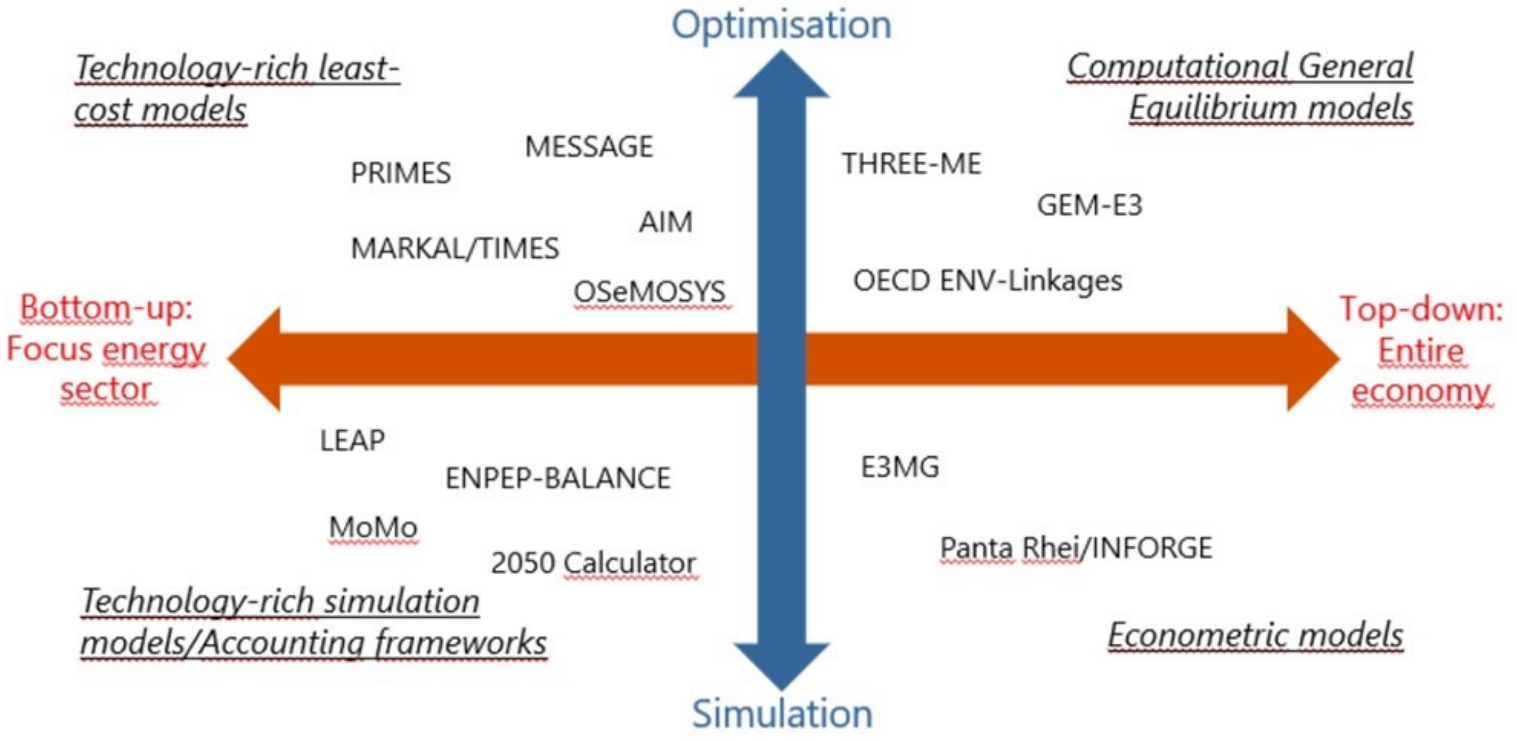


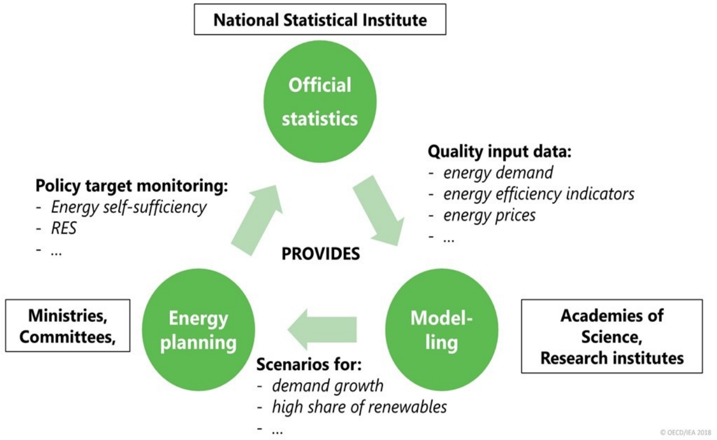
# BACKGROUND

What is energy modelling and what are the energy models in the UK?

# ENERGY MODELLING

**Energy modelling** refers to the process of using mathematical and computational models to analyze and predict various aspects of energy systems. It involves simulating the behavior and interactions of different energy sources, technologies, and policies to assess their impacts and inform decision-making.



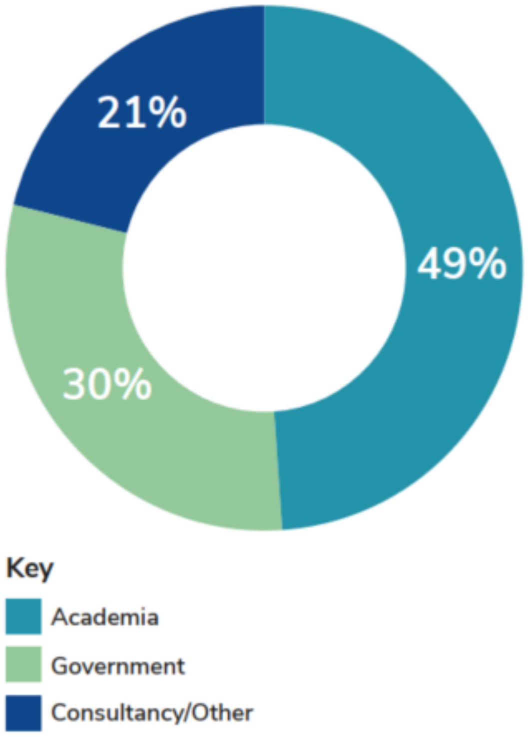


**Energy modelling** ≠

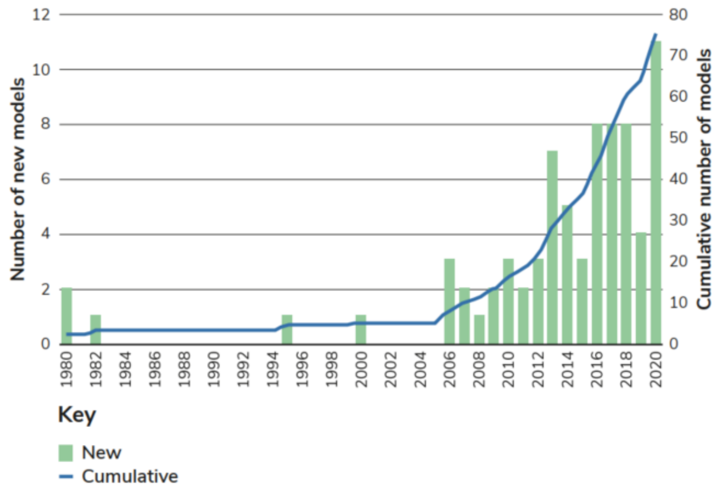
Source: https://www.energycharter.org/fileadmin/DocumentsMedia/EU4Energy/20180926_AZ_Energy_Strategy_MarkusFP_Introduction_to_energy_modelling_FINAL_EN.pdf

# ENERGY MODELS OF THE UK

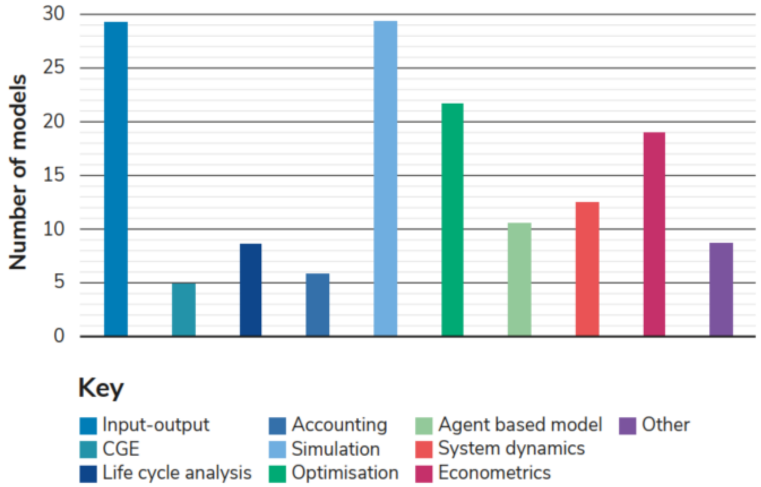
## UK energy models by host organization



## Development of UK energy modelling capacity



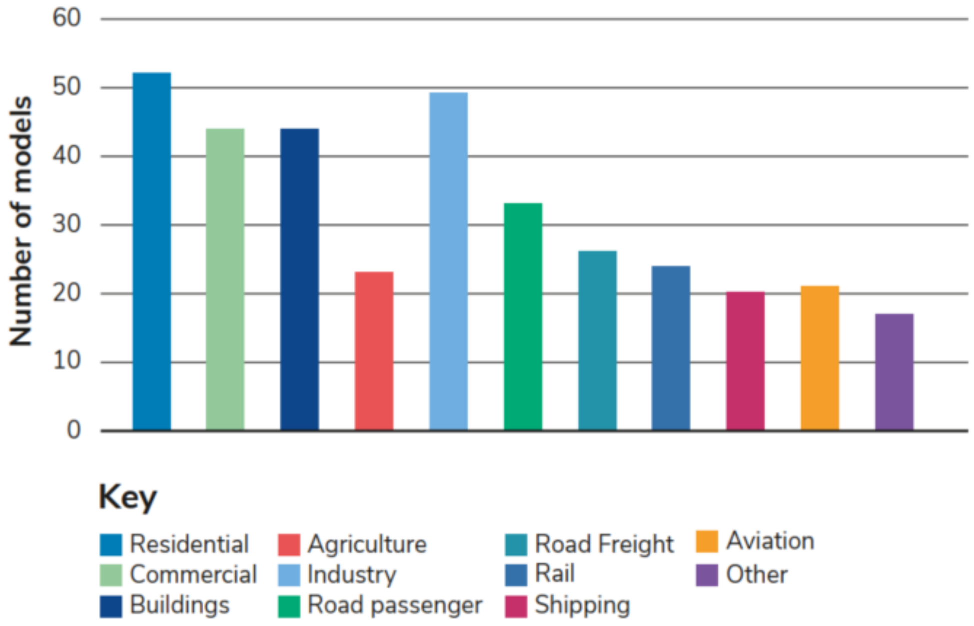
## Analytical methods of UK energy models



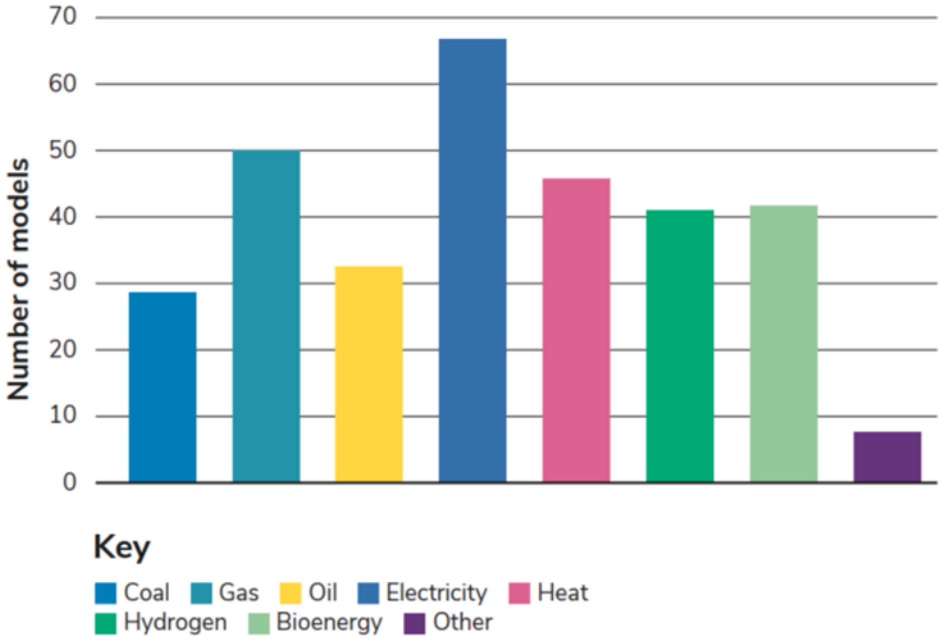
Source: Energy Modelling in the UK Briefing paper1: The modelling landscape

# ENERGY MODELS OF THE UK

## Sectoral coverage of energy models



## Energy vector coverage of UK models



Source: Energy Modelling in the UK Briefing paper1: The modelling landscape

# TIME TRENDS OF MAJOR APPLICATION OF ENERGY MODELS

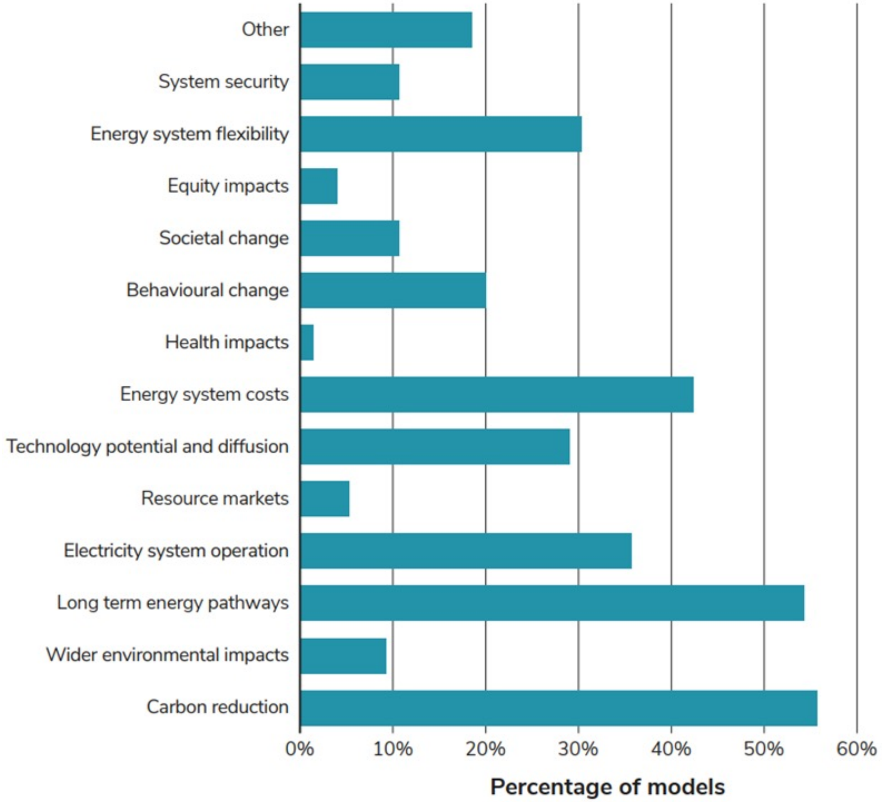
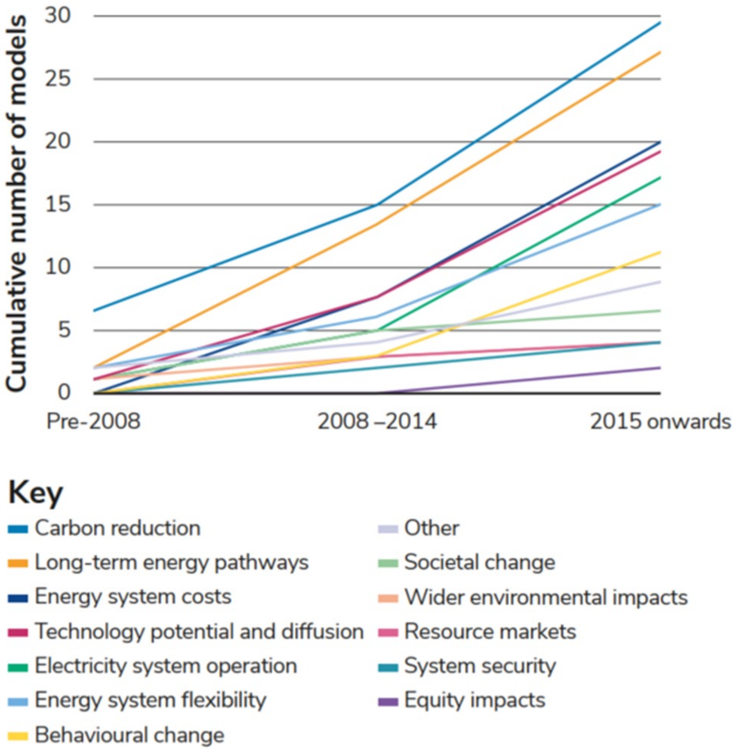


**Figure 9: Time trend of major applications of energy models**



Source: Energy Modelling in the UK Briefing paper1: The modelling landscape

# METHODOLOGY

Types and key Processes of energy modelling

# TECHNO-ECONOMIC ASSESSMENT

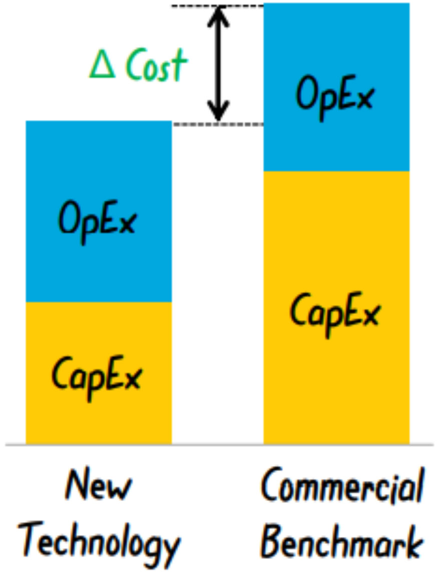
Techno-economic assessment is a method for evaluating the economic performance of a technology

Source: https://www.energy.gov/sites/default/files/2022-01/2022-01-19%20-%20Intro%20to%20TEA%20-%20Slides%20and%20Transcript_compliant_1_0.pdf

# MANUFACTURING COST COMPARISON

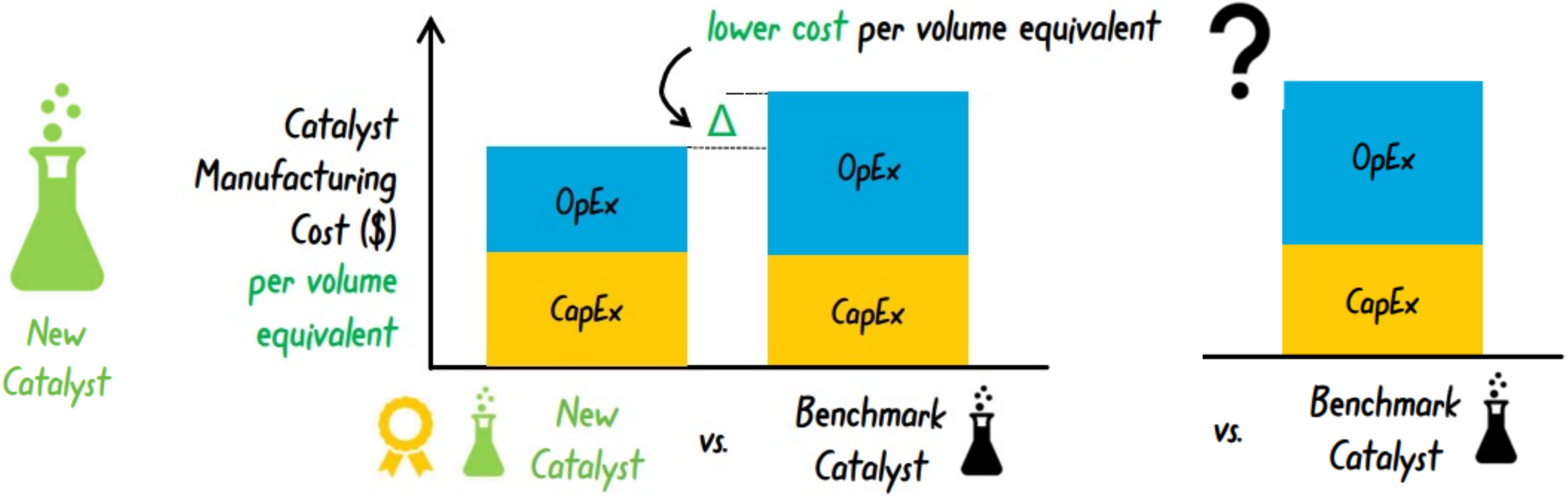
## Manufacturing Cost

## Cost Benchmarking



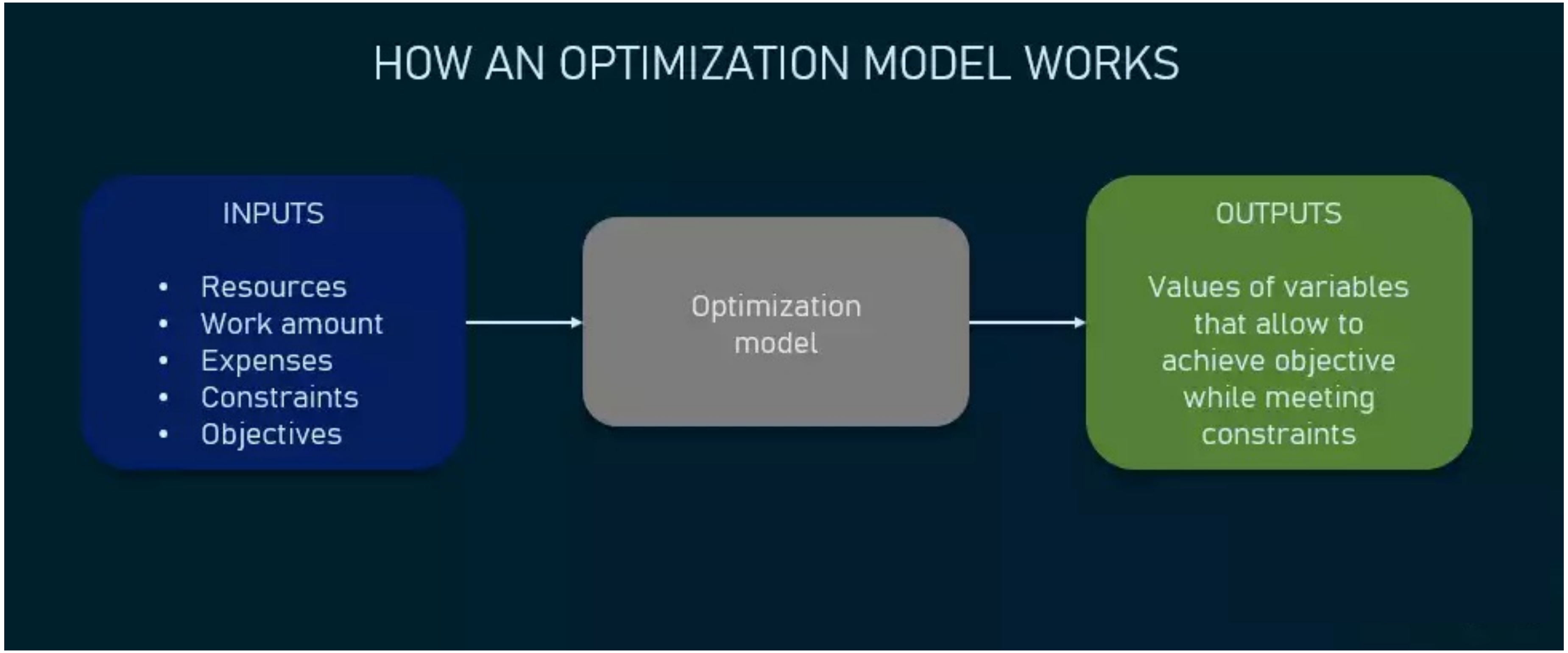
Source: https://www.energy.gov/sites/default/files/2022-01/2022-01-19%20-%20Intro%20to%20TEA%20-%20Slides%20and%20Transcript_compliant_1_0.pdf

# EXAMPLE
# COST COMPARISON: CATALYSTS FOR ETHYLENE MANUFACTURING



Source: https://www.energy.gov/sites/default/files/2022-01/2022-01-19%20-%20Intro%20to%20TEA%20-%20Slides%20and%20Transcript_compliant_1_0.pdf

# OPTIMIZATION MODEL (BOTTOM-UP ENERGY MODEL)



HOW AN OPTIMIZATION MODEL WORKS

INPUTS

- Resources
- Work amount
- Expenses
- Constraints
- Objectives

Optimization model

OUTPUTS

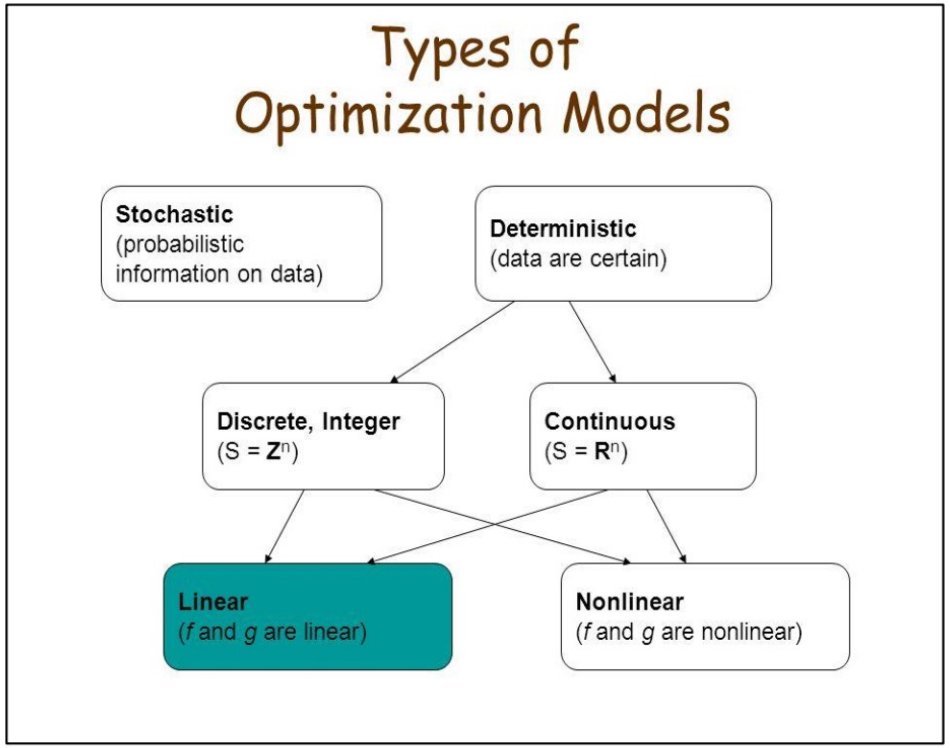
Values of variables that allow to achieve objective while meeting constraints

Source: https://www.altexsoft.com/blog/schedule-optimization/

# FEATURE OF OPTIMIZATION MODEL

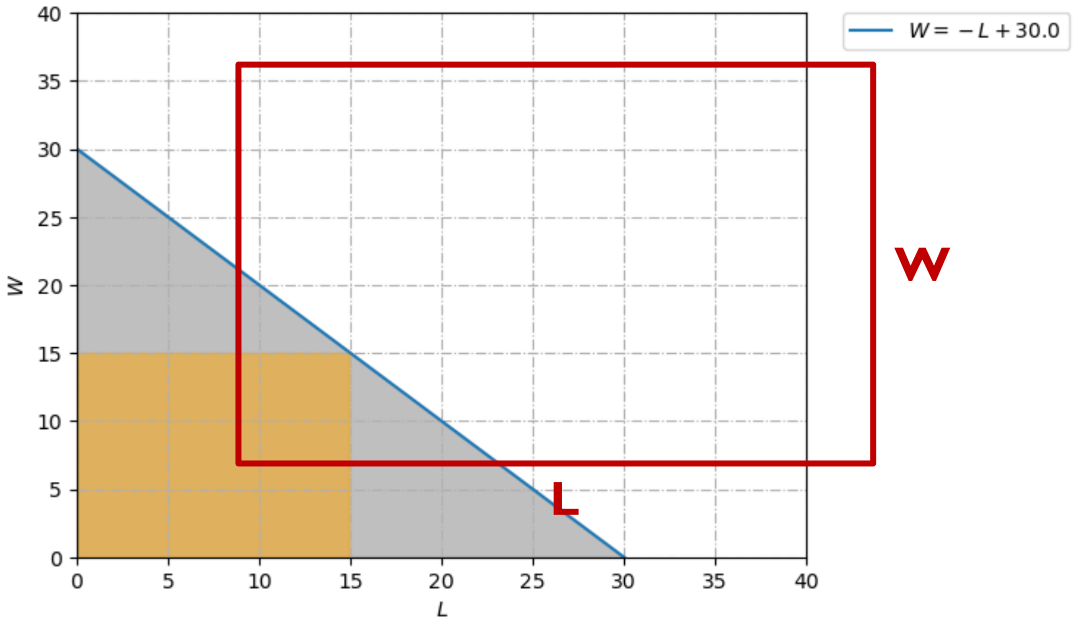
An optimization model has three main components:

- An objective function. This is the function that needs to be optimized.
- A collection of decision variables. The solution to the optimization problem is the set of values of the decision variables for which the objective function reaches its optimal value.
- A collection of constraints that restrict the values of the decision variables.



Source: https://old.mu.ac.in/wp-content/uploads/2017/10/Optimization-Models.pdf

# SIMPLE EXAMPLE OF OPTIMIZATION



- Example: You have 60 feet of fence available, and wish to enclose the largest rectangular area possible. What dimensions should you choose for the fenced-off area?
- Variables: Length – L, Width – W;
- Objectives: max L*W;
- Constraints:

$$2L + 2W \leq 60$$

$$L > 0$$

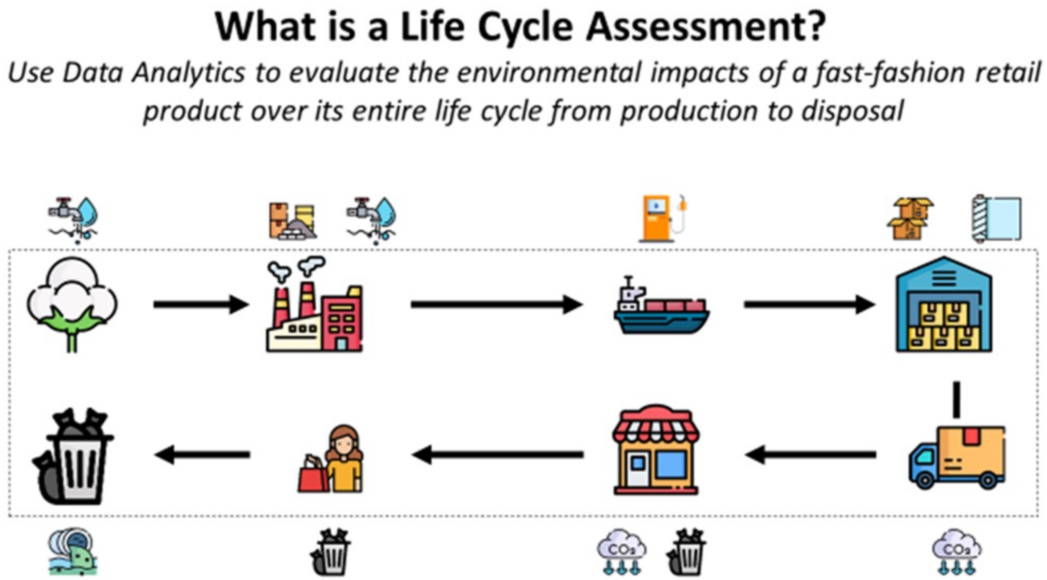
$$W > 0$$

- Result: when L=W=15, max area = 225

Source: Basic Optimization Concepts. CE 377K. Stephen D. Boyles. Spring 2015.

# LIFE CYCLE ASSESSMENT (LCA)

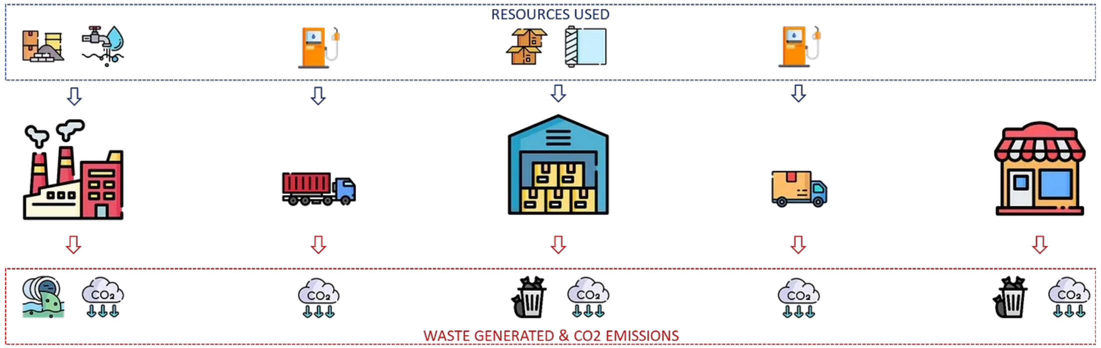
What is a Life Cycle Assessment?



**What is a Life Cycle Assessment?**

*Use Data Analytics to evaluate the environmental impacts of a fast-fashion retail product over its entire life cycle from production to disposal*

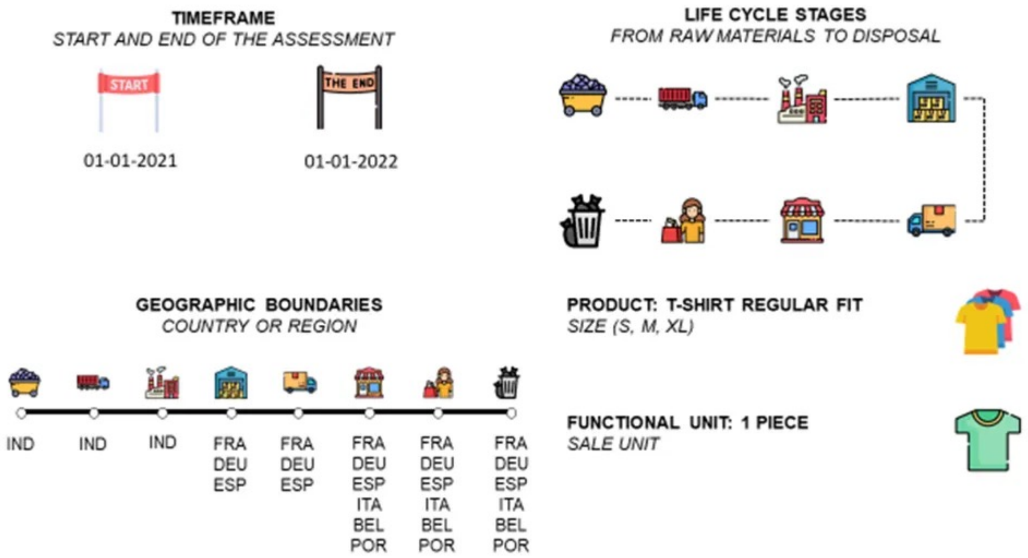
What is the environmental impact of the cheap t-shirt?



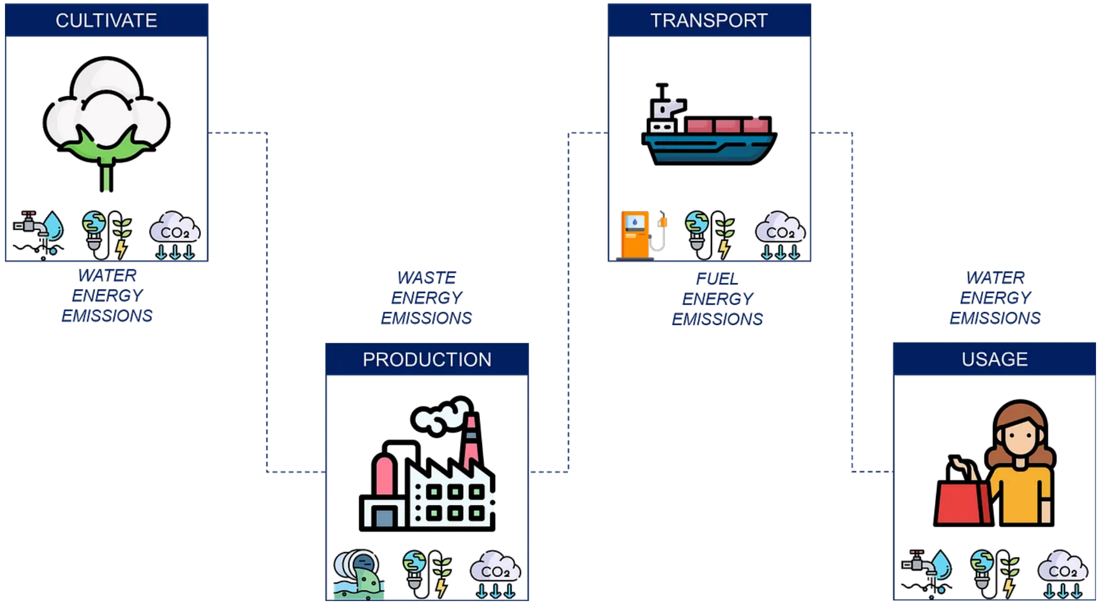
Source: https://www.bpf.co.uk/sustainable_manufacturing/life-cycle-analysis-lca.aspx

# FOUR STEPS OF LCA

## 1. Goal and scope definition



## 2. Inventory Analysis



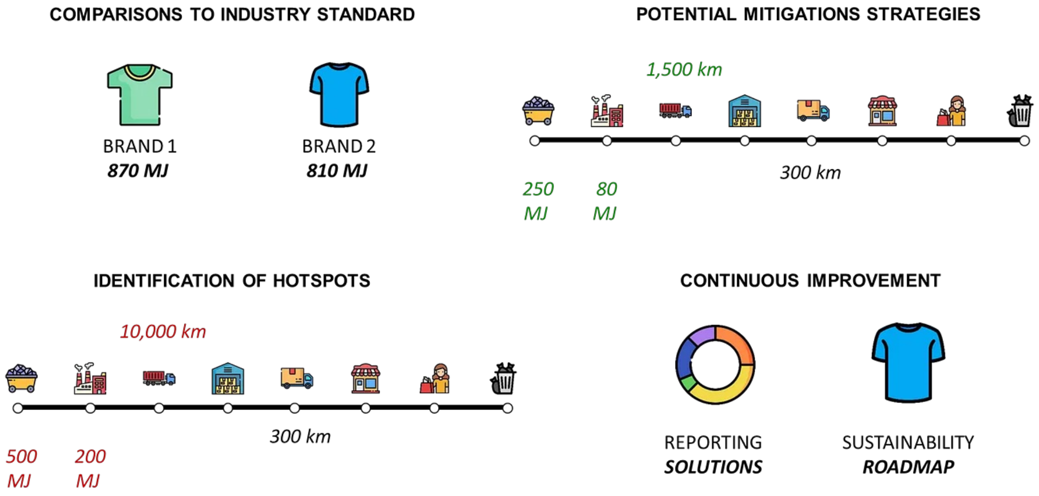
Source: https://www.bpf.co.uk/sustainable_manufacturing/life-cycle-analysis-lca.aspx

# FOUR STEPS OF LCA

## 3. Impact assessment

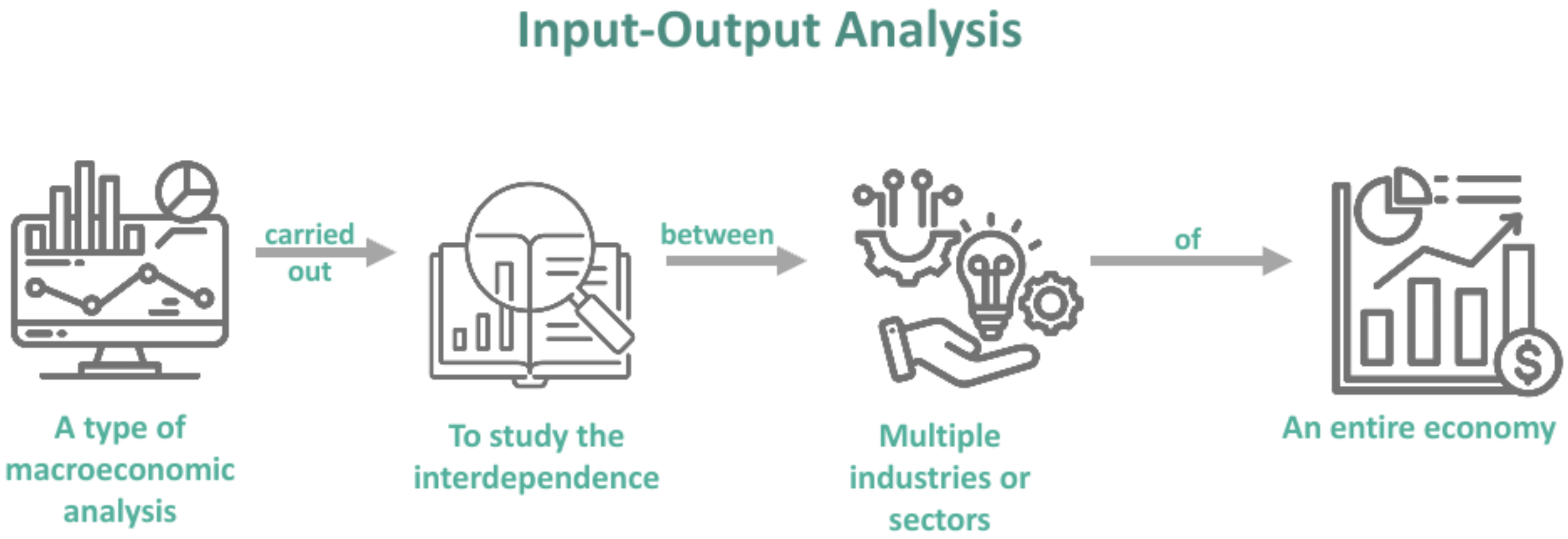
- Energy consumption: 870 MJ -- *58% consumed during the production*
- Greenhouse gas emissions: 46 kg CO2e -- *With a majority of emissions during production*
- Water consumption: 3,500 L -- *57% consumed during production*
- Solid waste: 0.5 kg -- *generated during production*
- Air pollution: 0.8 g of SOx and 0.5 g of NOx emissions -- *emitted during transportation*

## 4. Interpretation and evaluation



Source: https://www.bpf.co.uk/sustainable_manufacturing/life-cycle-analysis-lca.aspx

# INPUT-OUTPUT ANALYSIS (TOP-DOWN ENERGY MODEL)

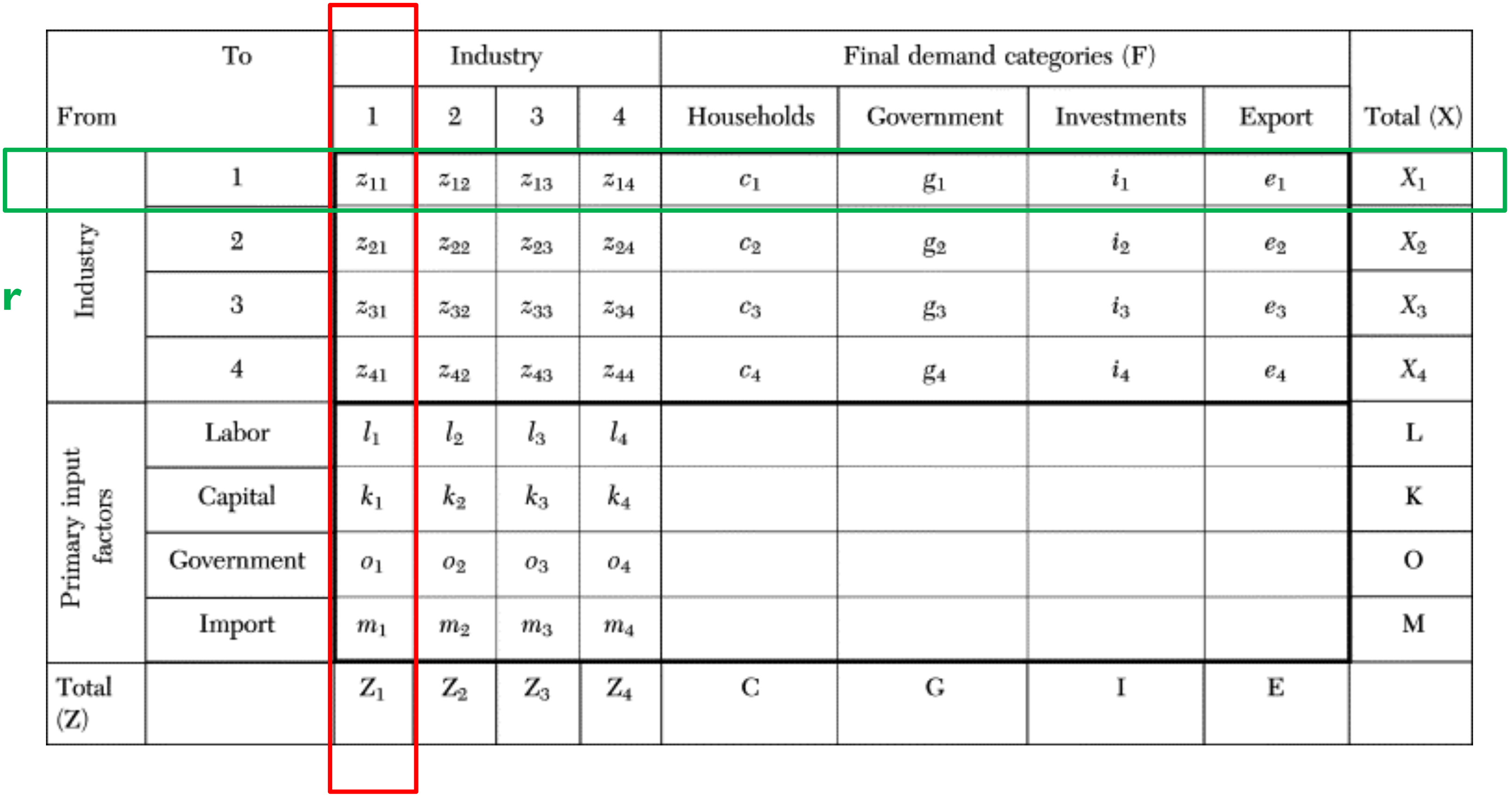


Source: https://www.wallstreetmojo.com/input-output-analysis/

# INPUT-OUTPUT TABLE EXAMPLE

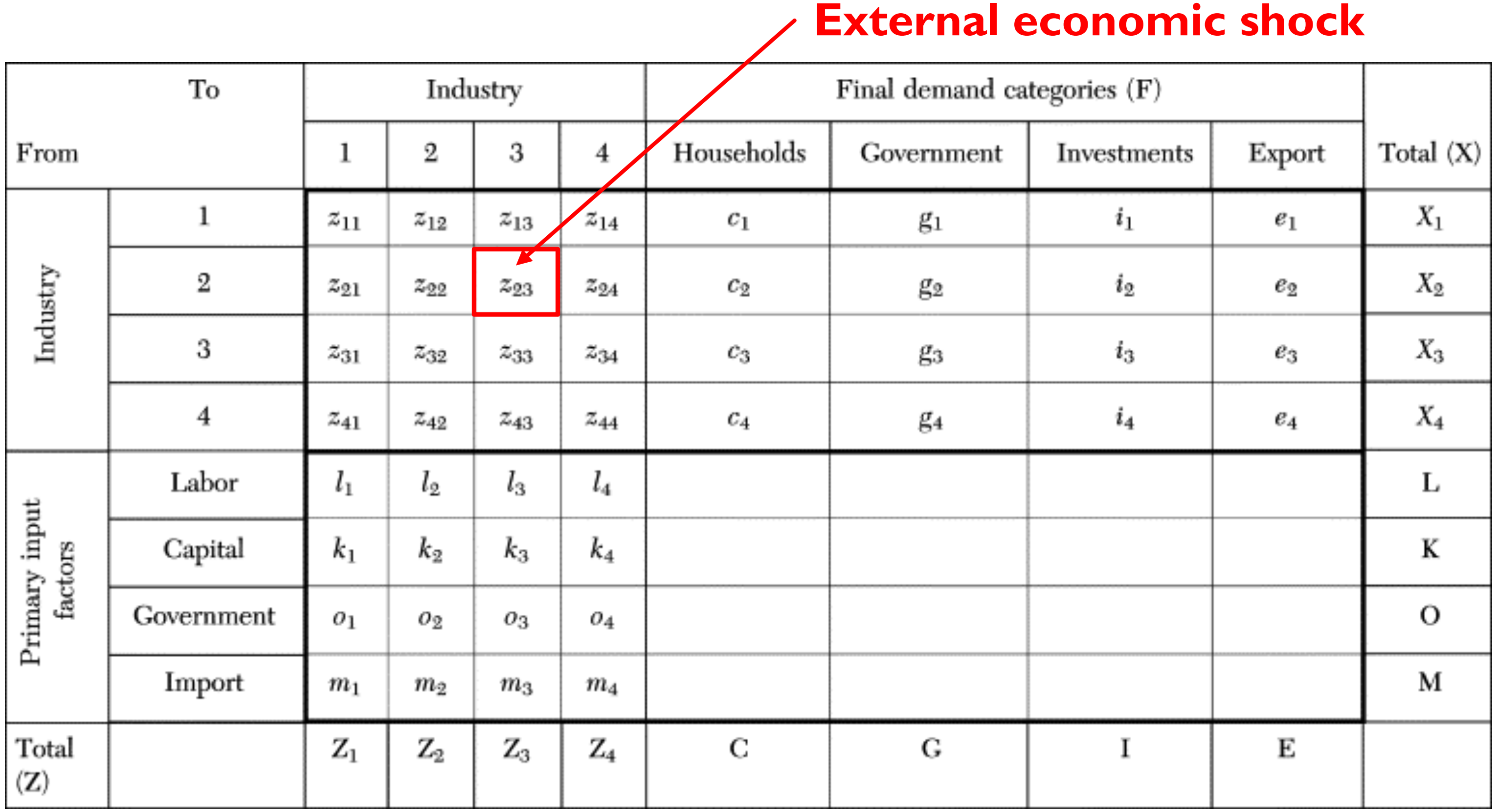
Input flow from other industries to Industry 1

Output flow from Industry 1 to other industries



| | To | Industry | | | | Final demand categories (F) | | | | Total (X) |
|---|---|---|---|---|---|---|---|---|---|---|
| From | | 1 | 2 | 3 | 4 | Households | Government | Investments | Export | |
| Industry | 1 | $z_{11}$ | $z_{12}$ | $z_{13}$ | $z_{14}$ | $c_1$ | $g_1$ | $i_1$ | $e_1$ | $X_1$ |
| | 2 | $z_{21}$ | $z_{22}$ | $z_{23}$ | $z_{24}$ | $c_2$ | $g_2$ | $i_2$ | $e_2$ | $X_2$ |
| | 3 | $z_{31}$ | $z_{32}$ | $z_{33}$ | $z_{34}$ | $c_3$ | $g_3$ | $i_3$ | $e_3$ | $X_3$ |
| | 4 | $z_{41}$ | $z_{42}$ | $z_{43}$ | $z_{44}$ | $c_4$ | $g_4$ | $i_4$ | $e_4$ | $X_4$ |
| Primary input factors | Labor | $l_1$ | $l_2$ | $l_3$ | $l_4$ | | | | | L |
| | Capital | $k_1$ | $k_2$ | $k_3$ | $k_4$ | | | | | K |
| | Government | $o_1$ | $o_2$ | $o_3$ | $o_4$ | | | | | O |
| | Import | $m_1$ | $m_2$ | $m_3$ | $m_4$ | | | | | M |
| Total (Z) | | $Z_1$ | $Z_2$ | $Z_3$ | $Z_4$ | C | G | I | E | |

# INPUT-OUTPUT TABLE EXAMPLE



**External economic shock**

| To | | Industry | | | | Final demand categories (F) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| From | | 1 | 2 | 3 | 4 | Households | Government | Investments | Export | Total (X) |
| Industry | 1 | $z_{11}$ | $z_{12}$ | $z_{13}$ | $z_{14}$ | $c_1$ | $g_1$ | $i_1$ | $e_1$ | $X_1$ |
| | 2 | $z_{21}$ | $z_{22}$ | $z_{23}$ | $z_{24}$ | $c_2$ | $g_2$ | $i_2$ | $e_2$ | $X_2$ |
| | 3 | $z_{31}$ | $z_{32}$ | $z_{33}$ | $z_{34}$ | $c_3$ | $g_3$ | $i_3$ | $e_3$ | $X_3$ |
| | 4 | $z_{41}$ | $z_{42}$ | $z_{43}$ | $z_{44}$ | $c_4$ | $g_4$ | $i_4$ | $e_4$ | $X_4$ |
| Primary input factors | Labor | $l_1$ | $l_2$ | $l_3$ | $l_4$ | | | | | L |
| | Capital | $k_1$ | $k_2$ | $k_3$ | $k_4$ | | | | | K |
| | Government | $o_1$ | $o_2$ | $o_3$ | $o_4$ | | | | | O |
| | Import | $m_1$ | $m_2$ | $m_3$ | $m_4$ | | | | | M |
| Total (Z) | | $Z_1$ | $Z_2$ | $Z_3$ | $Z_4$ | C | G | I | E | |

- External economic shocks result in the unbalance of the I-O table;
- I-O table has to be rebalanced to reveal the influence on the whole economic system.
- I-O table can also be extended to analyze environmental impacts, such as carbon emission and air pollution and energy consumption.

# EXAMPLE

## External Shock

- Energy prices surged 20%
- The price of each barrel of crude oil increased and averaged $106.96, up by 15.3% (used to be $92.77).

## Direct Impact

- Consumers primarily purchase less durable goods, such as new houses and cars;
- Firms minimize their investment spending owing to uncertainty.

## Spillover Effect

- Impact on real GDP;
- Lead to a fall in social surplus, decelerating economic growth;
- Result in higher global costs.

Source: https://www.wallstreetmojo.com/input-output-analysis/

# KEY PROCESSES OF ENERGY MODELLING

**Data Collection and Validation**

1. Data on energy demand, supply, prices, technology performance, and environmental factors;
2. Ensure data quality and consistency.

**Assumptions and Scenario Development**

1. Assume future conditions;
2. Explore different potential futures.

**Model Formulation and Calibration**

1. Formulate mathematical equations and algorithms that simulate energy flows, technology dynamics, and policy interactions;
2. Ensure that the models accurately reflect real-world behavior.

**Sensitivity Analysis and Uncertainty Assessment**

1. Analyze the sensitivity of results to changes in input parameters and assumptions.
2. Identify the key drivers and uncertainties in the model's outcomes.
3. Uncertainty assessment techniques, e.g. Monte Carlo simulations.

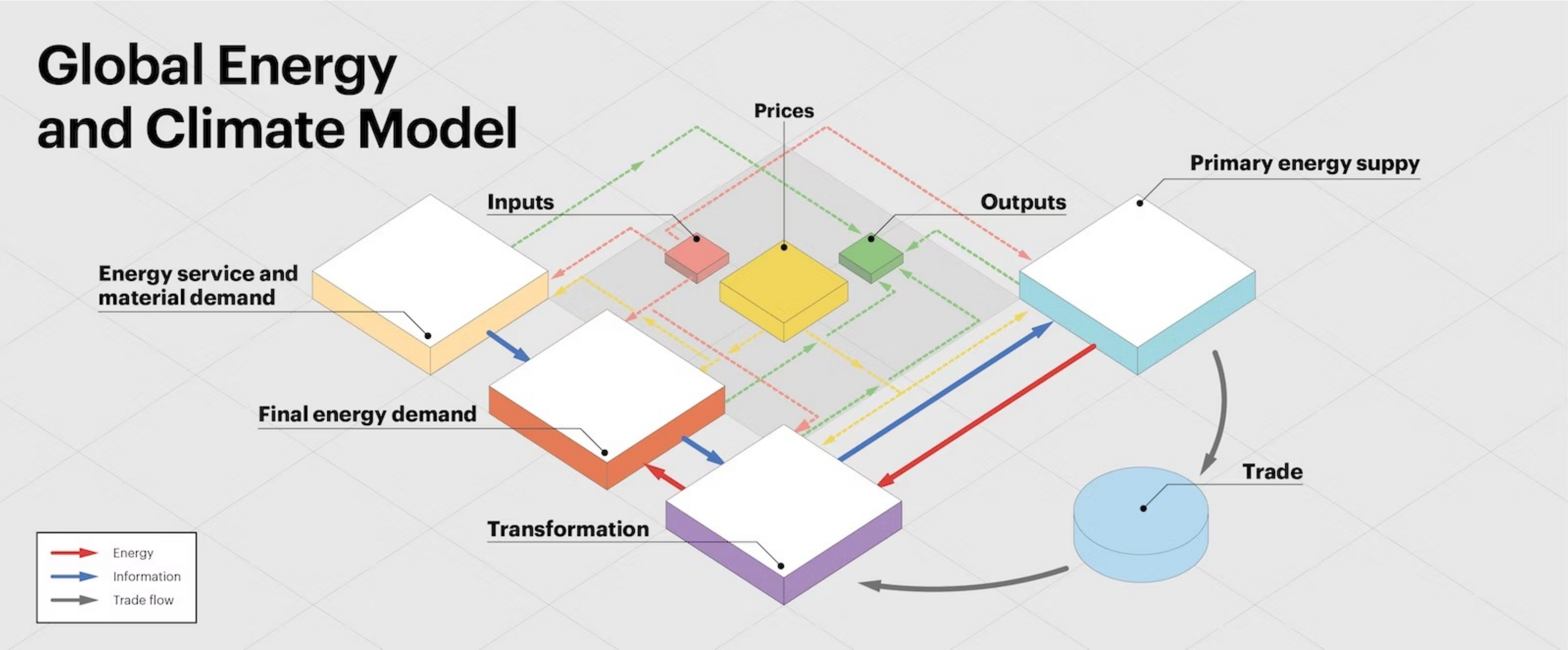
**Output Analysis and Interpretation**

1. Evaluate the impacts of different scenarios;
2. Assess key performance indicators;
3. Identify trade-offs and synergies among various objectives, such as cost, emissions, and energy security.

# APPLICATIONS

Case study and future trends

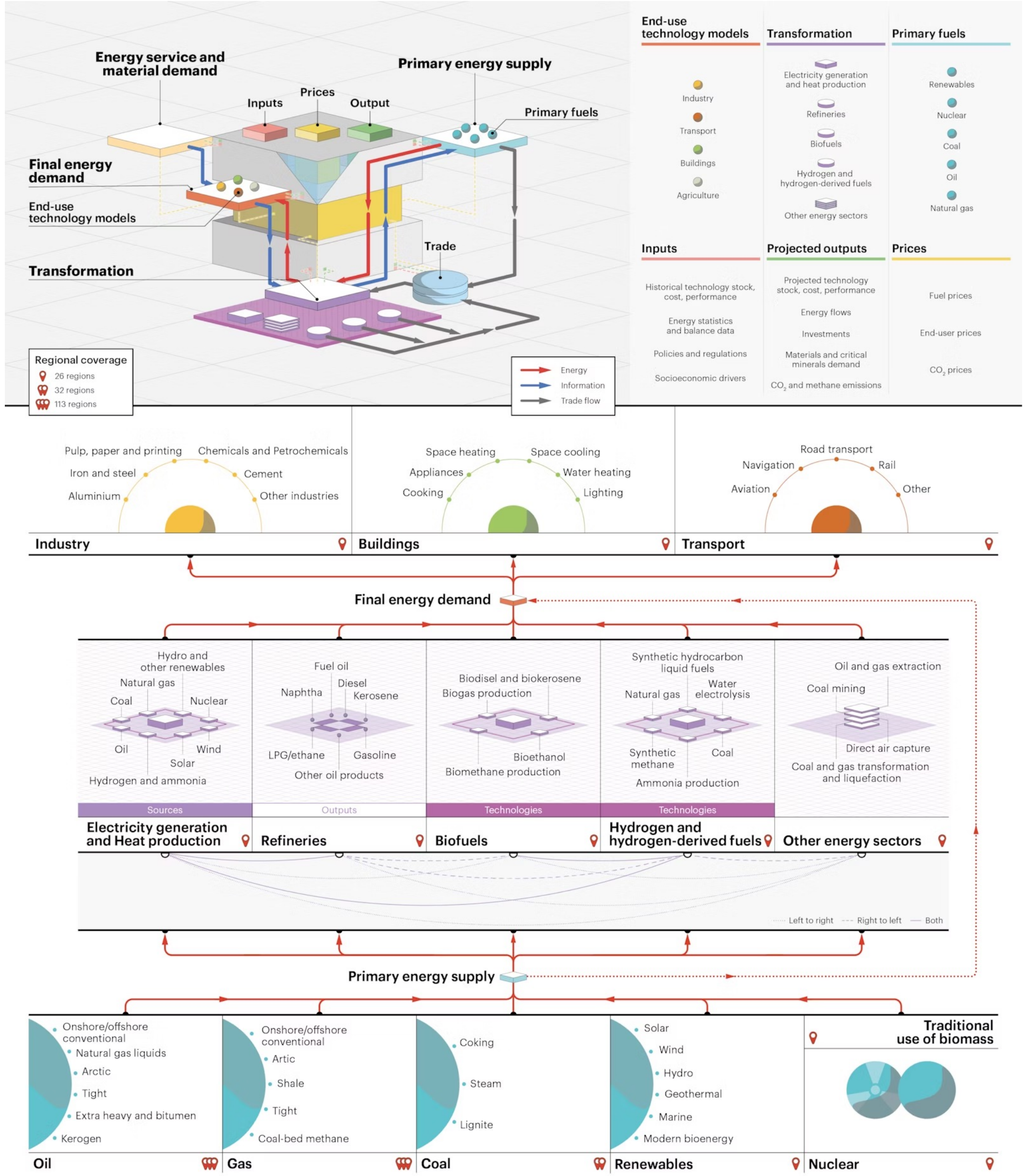
# IEA'S GLOBAL ENERGY AND CLIMATE (GEC) MODEL



Source: https://www.iea.org/reports/global-energy-and-climate-model/about-the-global-energy-and-climate-model

# IEA’S GLOBAL ENERGY AND CLIMATE (GEC) MODEL

- **Final energy demand**, covering industry, transport, buildings, agriculture and other non-energy use. This is driven by detailed modelling of energy service and material demand.
- **Energy transformation**, including electricity generation and heat production, refineries, the production of biofuels, hydrogen and hydrogen-derived fuels and other energy-related processes, as well as related transmission and distribution systems, storage and trade.
- **Energy supply**, including fossil fuels exploration, extraction and trade, and availability of renewable energy resources.
- **Inputs** to the model include: historical technology stock, cost and performance; energy statistics and balance data; policies and regulations; and socio-economic drivers.
- **Outputs** from the model include: projected technology stock, cost, and performance; energy flows by fuel; investment needs and costs; materials and critical minerals demand; CO2 and methane emissions.
- **Prices**, which are both inputs and outputs of the model, include: fuel, end-user and CO2 prices.



Source: https://www.iea.org/reports/global-energy-and-climate-model/about-the-global-energy-and-climate-model

# CAPABILITIES AND FEATURES OF GEC MODEL

**Global and regional energy trends:**

- This includes assessment of energy demand, supply availability and constraints, international trade and energy balances by sector and by fuel;

**Environmental impact of energy use:**

- CO2 emissions from fuel combustion, CO2 process emissions, Methane from oil and gas operations are measured, which makes it possible to publish the CO2-equivalend emissions for the entire energy sector;
- Local air pollutants are also estimated and the temperature outcomes of modelled scenarios are assessed.

**Policy and technology developments:**

- Alternative scenarios analyze the impact of a range of policy actions and technological developments on energy demand, supply, trade, investments and emissions.

Source: https://www.iea.org/reports/global-energy-and-climate-model/about-the-global-energy-and-climate-model

# TAKEAWAYS

Takeaways from today's workshop

# TAKEAWAYS

## Background

- Energy modelling does not predict the future, but provides insight for policy decisions and discussions;
- Choice of energy modelling tools is defined by the question to be analysed;
- A general change happened in the discourse from predominantly supply-side techno-economic solutions to more inclusive solutions that also consider societal and political factors.

## Methodology

- Environmentally Extended Input-Output Analysis (EEIOA), which takes environment-related inputs into account by adding additional columns of inputs such as gasoline and coals.
- Life cycle thinking is important when evaluating the emission of a product or process;
- Optimization is the process of improving operational parameter, algorithm or energy system to reduce costs/emissions or increase efficiency/profit.

## Application

- Models are being developed to assess the impact of renewable energy integration on grid stability, energy costs, and environmental sustainability;

# THANK YOU

# Q & A

Jiatai Wang

jiatai.wang@surrey.ac.uk

www.surrey.ac.uk/ces

# GROUP DISCUSSION

## SOLVING PROBLEMS

# BREAK

# GROUP DISCUSSION

## ENERGY MODELLING TOOLS

# SURVEY

## Please Complete The Survey Sheet

# END

## Thank you for attending this workshop