

Introduction to the TIMES modelling approach

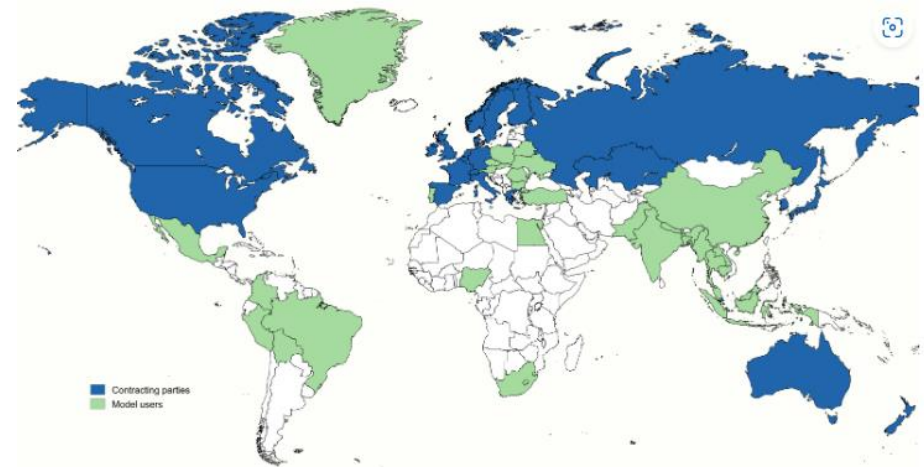
From mathematical modelling to insights for decision-making

TCP-ETSAP & TCP-IETS Joint workshop

April 10, 2025

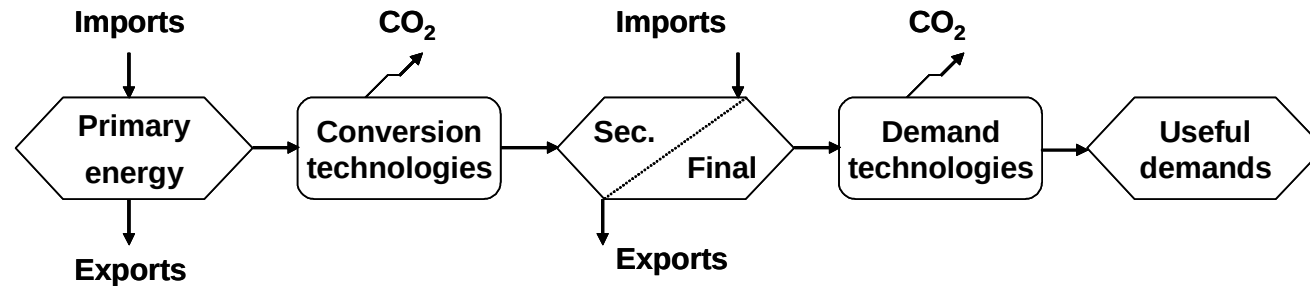
TIMES history

- TIMES is developed within the Energy Technology Systems Analysis Programme (**ETSAP**) of the **International Energy Agency (IEA)** since 1978: **45 years**
 - After the first oil crisis
 - To provide countries with a common platform to examine technology innovations and policy priorities
 - Even more relevant now for climate change mitigation
- Rich history of applications to support decision making in **70 countries** (> 1000 scientific papers)
- **Canadian** researchers at GERAD are among the prime developers



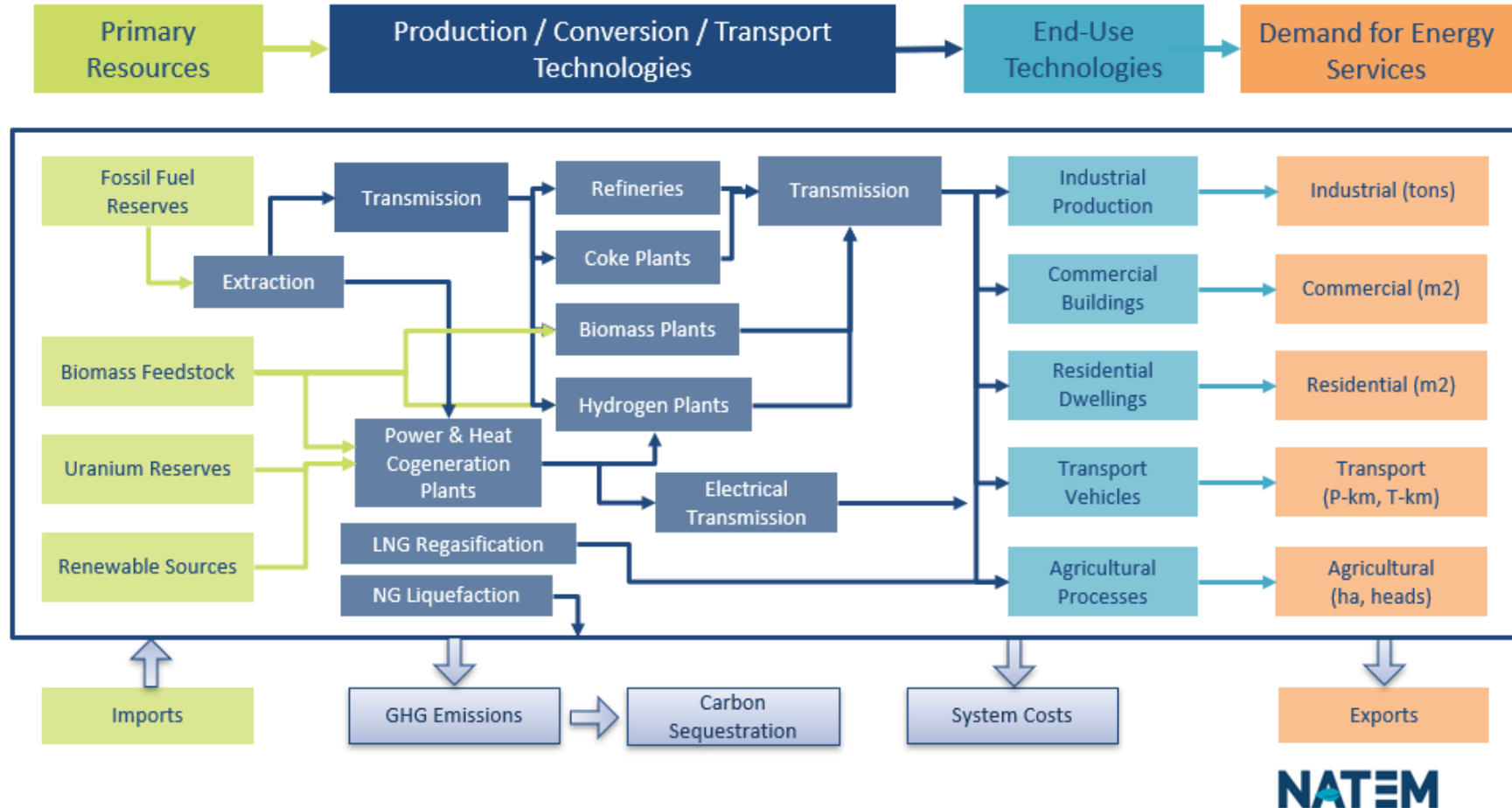
TIMES features

- **Demand driven:** Account for multiple demands for energy services in all end-use sectors: passengers-km, tons of cement, square meters of commercial buildings, etc.
- **Integrated energy systems:** capture the whole energy system (multi-fuel, multi-sector, multi-region)
- Energy systems are represented with **many details and numerous technologies**, as well as energy/material commodity flows



- **Dynamic model:** over 30 to 50 years to capture long term structural changes (or even 100 years for climate policies)

Detailed representations of energy systems



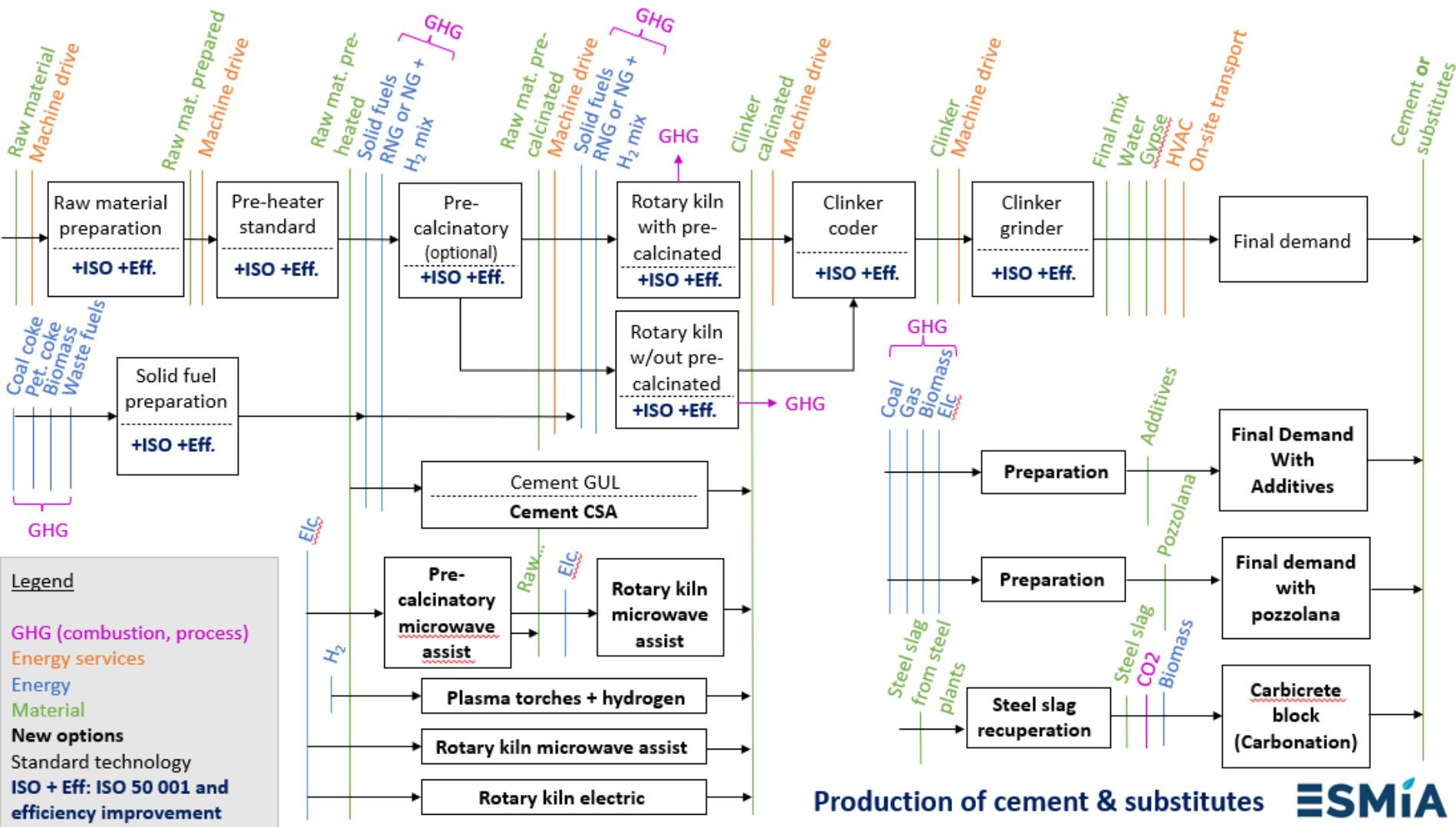
The North American TIMES Energy Model (NATEM) example:

- 75 energy service demands
- >5000 technologies
- >500 commodities (energy, material, and emission)

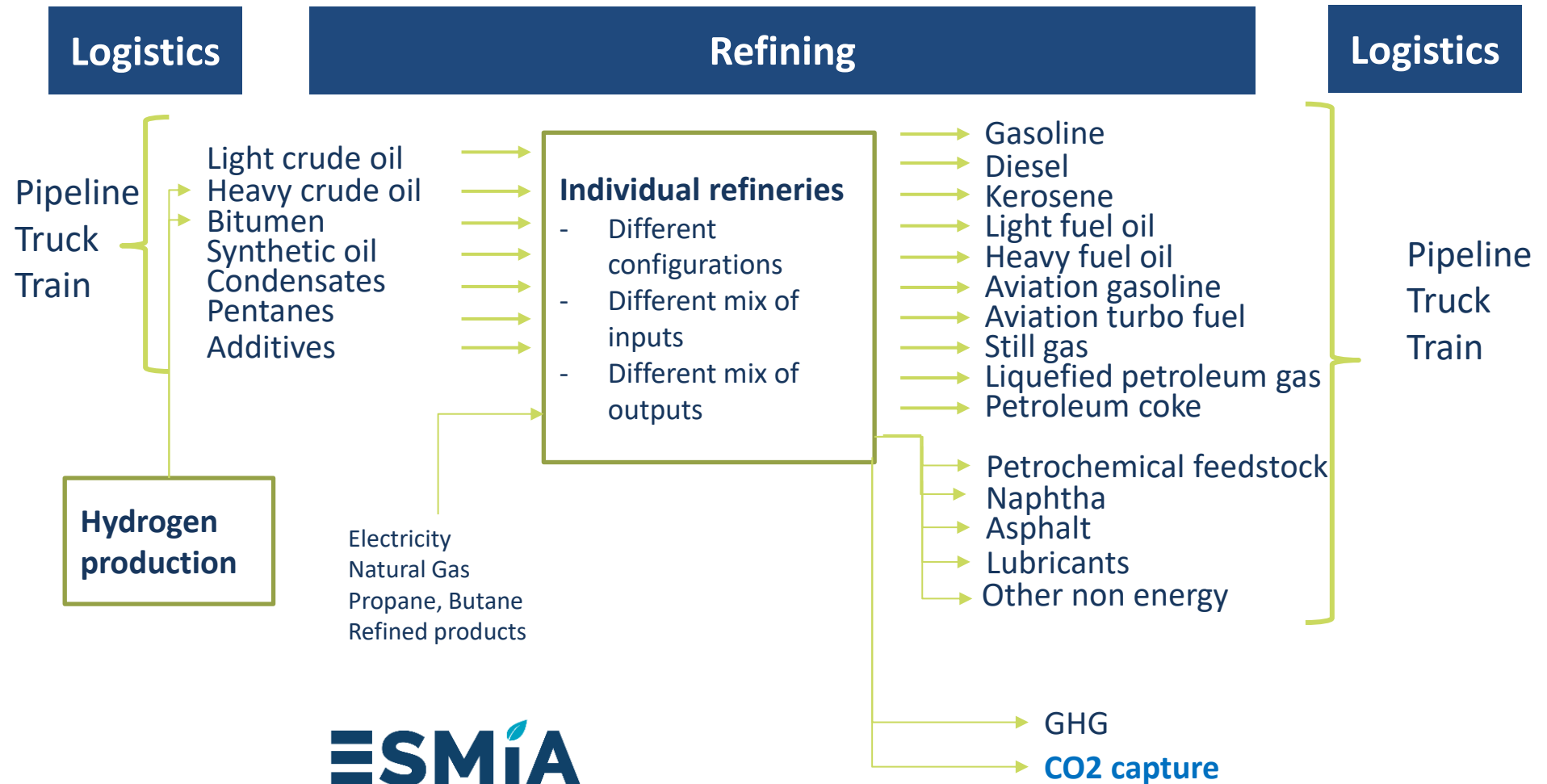
Ex. Detailed sector

+ Technologies in competition for:

- CCS
- energy services



Ex. Simplistic sector



Space and time dimensions

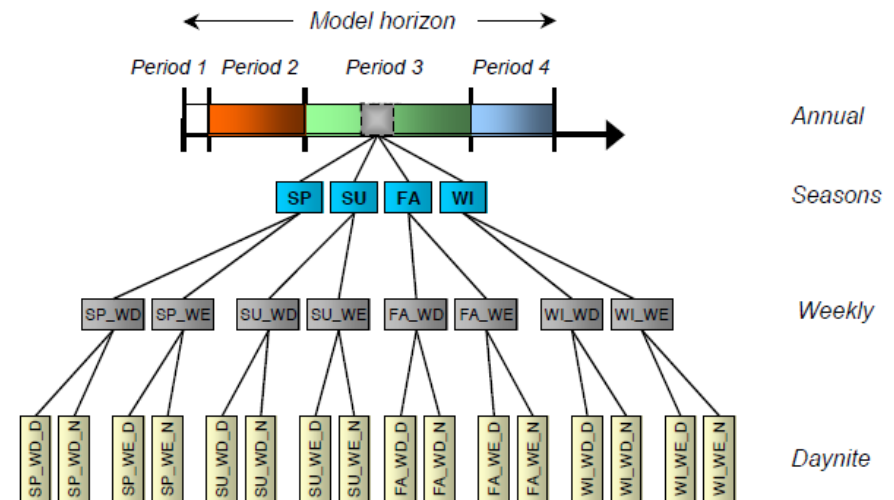
Space

- Uni- or multiregional models
- Geographical scales:
 - Global
 - Continental
 - National
 - Regional (states, counties, etc.)
 - Cities
 - Districts

Time

- Base year
- Annual data
- Annual time periods of variable lengths
- Milestone years (reported results)
- Time slices (seasons and intraday periods)
- Hourly levels

➤ What increases the most the solving time!



Source: Loulou et al (2016)

What can make results differ between models?

- Scope of energy system modelled and competition for clean resources
- Level of detail in the representation of energy systems
- Quality of input data and availabilities of information on the breakdown by energy services and/or technologies
 - Energy & material
 - Point sources of combustion and process emissions
- Spatial and temporal resolution
 - Electrification potential is better understood at the hour level
- Consideration of mitigation options (fuel switches, emerging technologies, material substitutes, demand reduction, etc.).
- Knowledge of operational constraints (formulation as constraints).

TIMES supply and demand equilibrium

- Partial equilibrium → only the energy market is considered
 - Quantities & prices of energy commodities are given by the model solution
 - These flows and prices are computed **at equilibrium**

Amount produced by suppliers = Amount purchased by consumers

- The model gives a solution that **maximizes net surplus**

Net surplus = Producer surplus + Consumer surplus

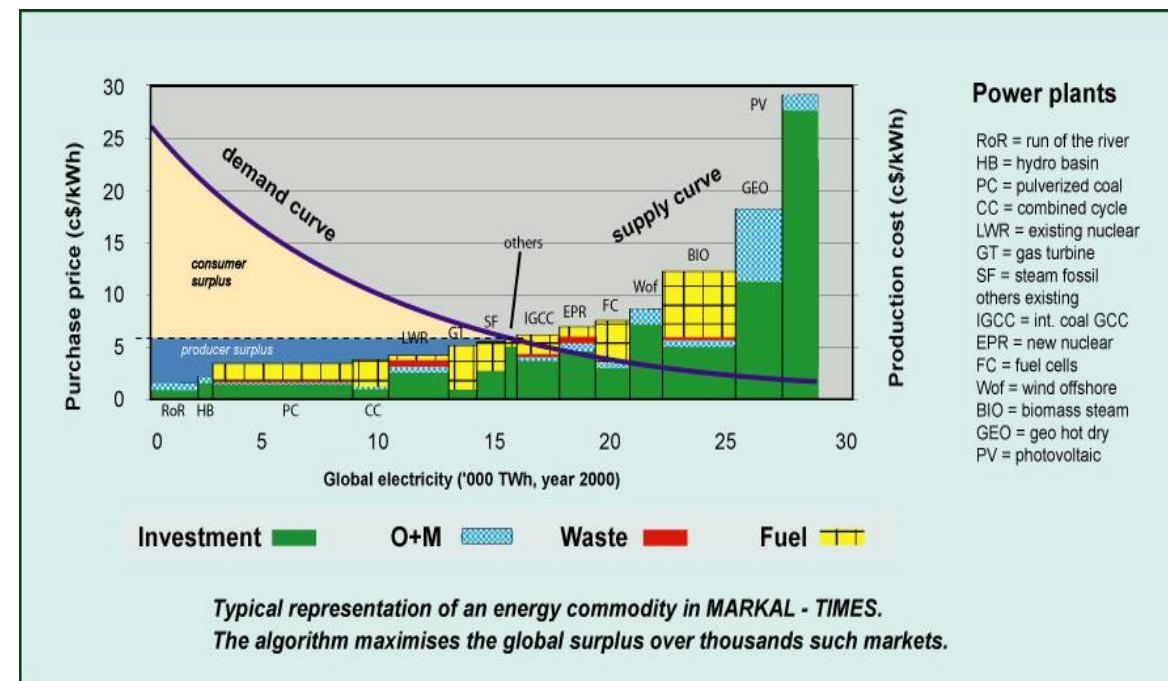
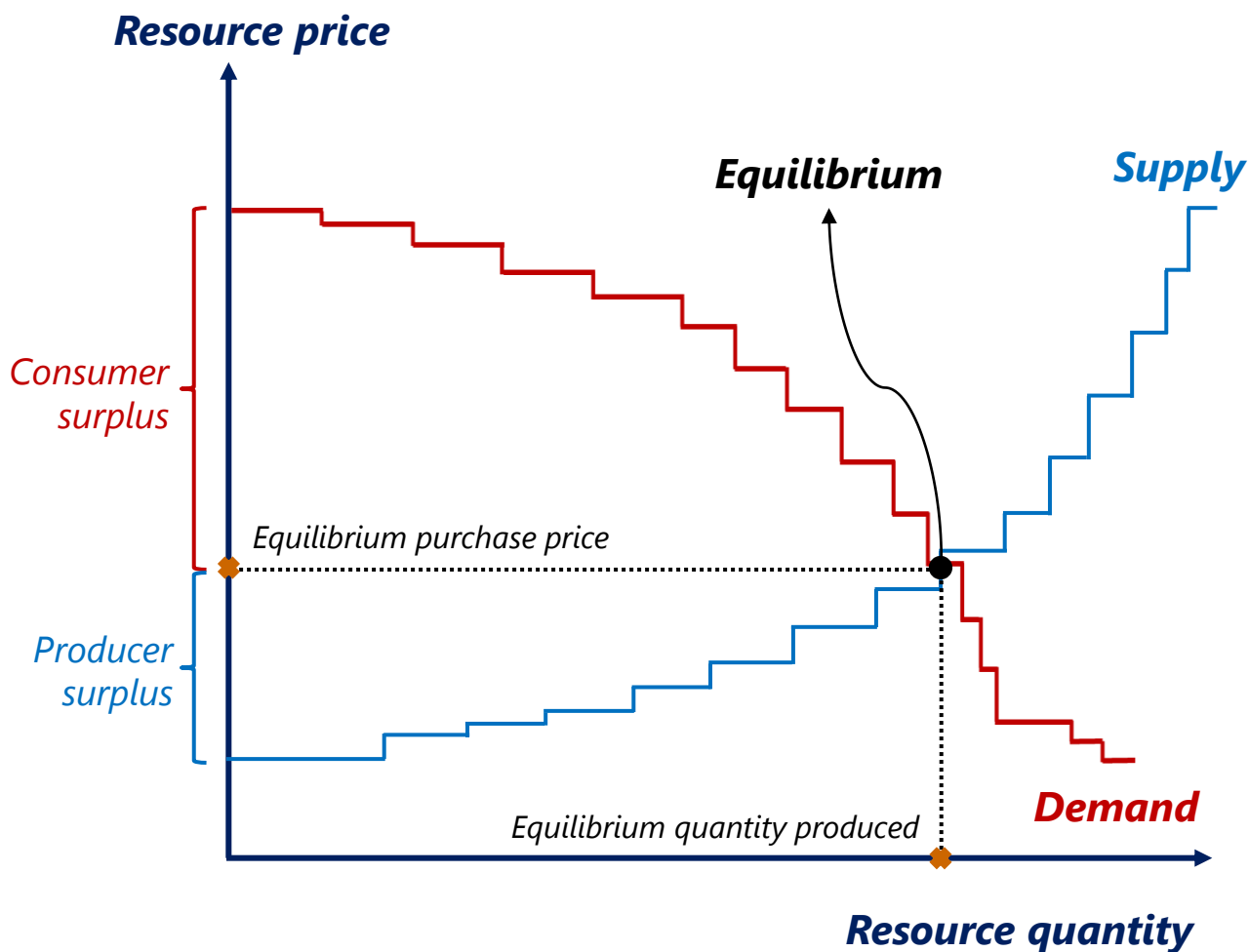
Producer surplus: *Profit*

Price that energy is sold at > Minimum price they are willing to sell for

Consumer surplus: *Gain*

Price that energy is bought at < Maximum price they are willing to pay

TIMES supply and demand equilibrium



Source: Loulou et al (2016)

TIMES optimization program

- Mathematical formulation of **decision-making** problems

What are the **best** actions I can take to achieve a target for a given system?

What are the values of x that maximize/minimize an objective function subject to constraints?

x $f(x)$ $g(x)$

- **Linear programming** (LP)
 - Subclass of optimization problems
 - **Both** $f(x)$ and $g(x)$ are linear functions of x
 - $f(x) = c^T x$
 - $g(x) := Ax = b$

$$\begin{array}{ll} \min_{x \in X} & c^T x \\ \text{s.t.} & Ax = b \end{array}$$

TIMES optimization program

- This is only a partial list!

$$\begin{array}{ll} \min_{x \in X} & c^T x \\ \text{s.t.} & Ax \leq b \end{array}$$

Decision variables (x)

- New capacity investments
- Total installed capacity
- Annual process activity
- Commodity flow in/out of process
- Commodity trade in/out of regions (import/export)
- End-use energy service demand
- ...

Objective function ($c^T x$)

- Capital costs for process investments/dismantling
- Fixed and variable operation and maintenance costs
- Import/export costs/revenues
- Commodity delivery costs
- Taxes and subsidies
- Salvage value
- ...

Constraints ($Ax = b$)

- Capacity transfer
- Activity definition
- Capacity-activity relations
- Commodity balance
- Efficiency definitions
- Flow shares
- Peak demand satisfaction
- User constraints (e.g. policy-driven)
- ...

TIMES objective function

$$NPV = \sum_{r=1}^R \sum_{y \in YEARS} (1 + d_{r,y})^{REFYR-y} \bullet ANNCOST(r, y)$$

where:

NPV

is the net present value of the total cost for all regions;

ANNCOST(r,y)

is the total annual cost in region r and year y;

$d_{r,y}$

is the general discount rate;

REFYR

is the reference year for discounting;

YEARS

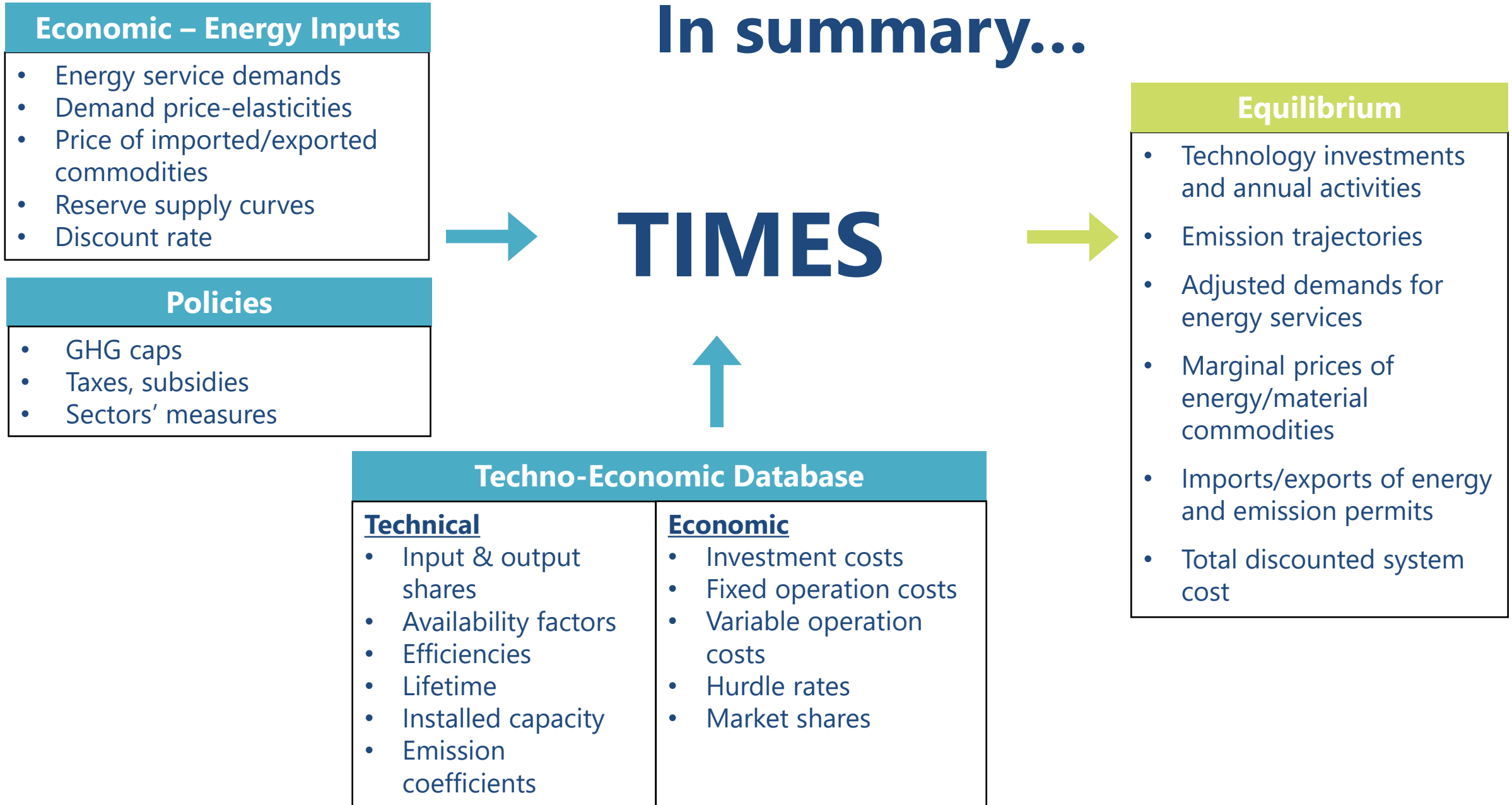
is the set of years for which there are costs
(in the horizon, plus past and before years EOH;

R

is the set of regions in the area of study

- Investment and dismantling costs are transformed into annual payments
- A salvage value of all investments still active at the end of the horizon (EOH) is calculated and its value is assigned to the (single) year following the EOH
- All other annual costs are added (ANNCOST)
- For each region, a total NPV is computed and discounted to the base year.
- Regional discounted costs are aggregated into a single total cost (OBJ)

In summary...



Questions?

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