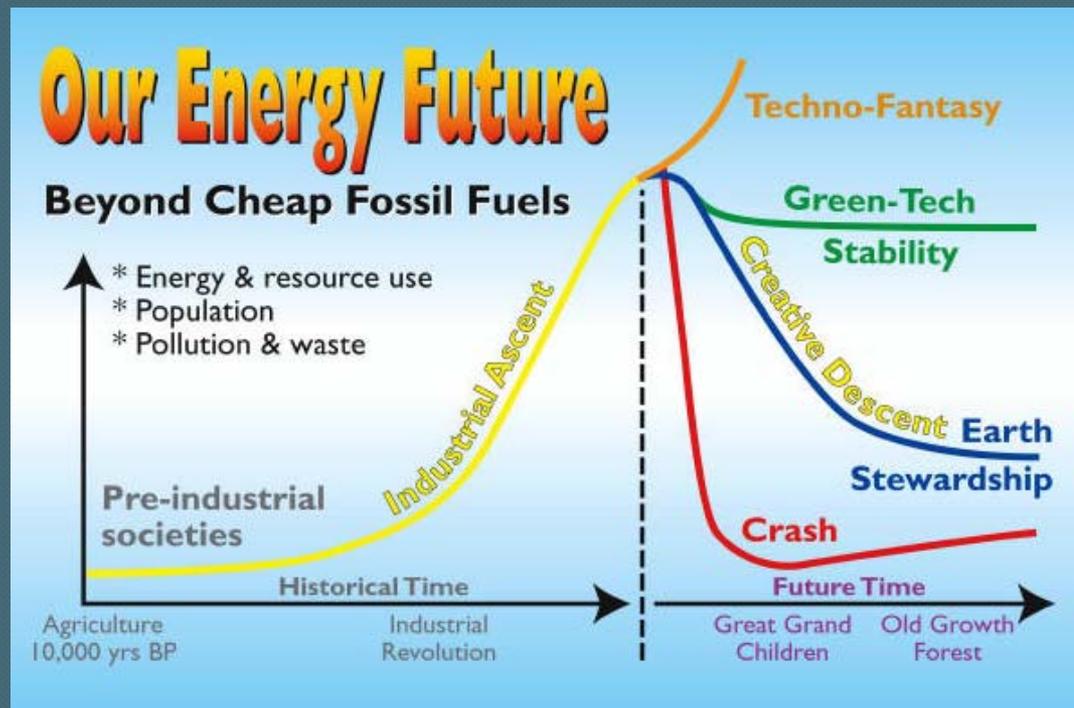# Global Energy Modelling –
a Biophysical Approach:
G.E.M.B.A

Michael Dale
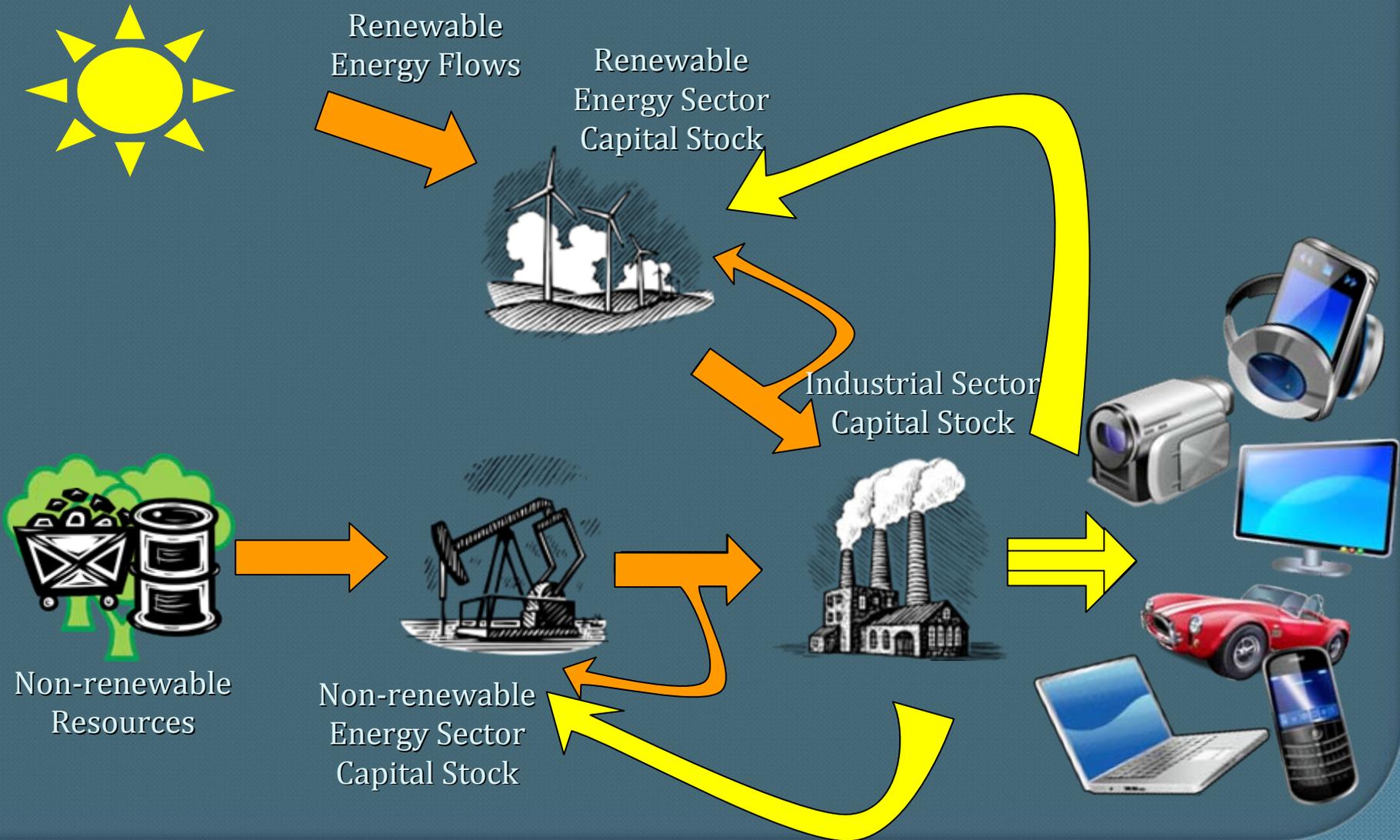University of Canterbury
Mechanical Engineering

Supervisor: Assoc. Prof. Susan Krumdieck
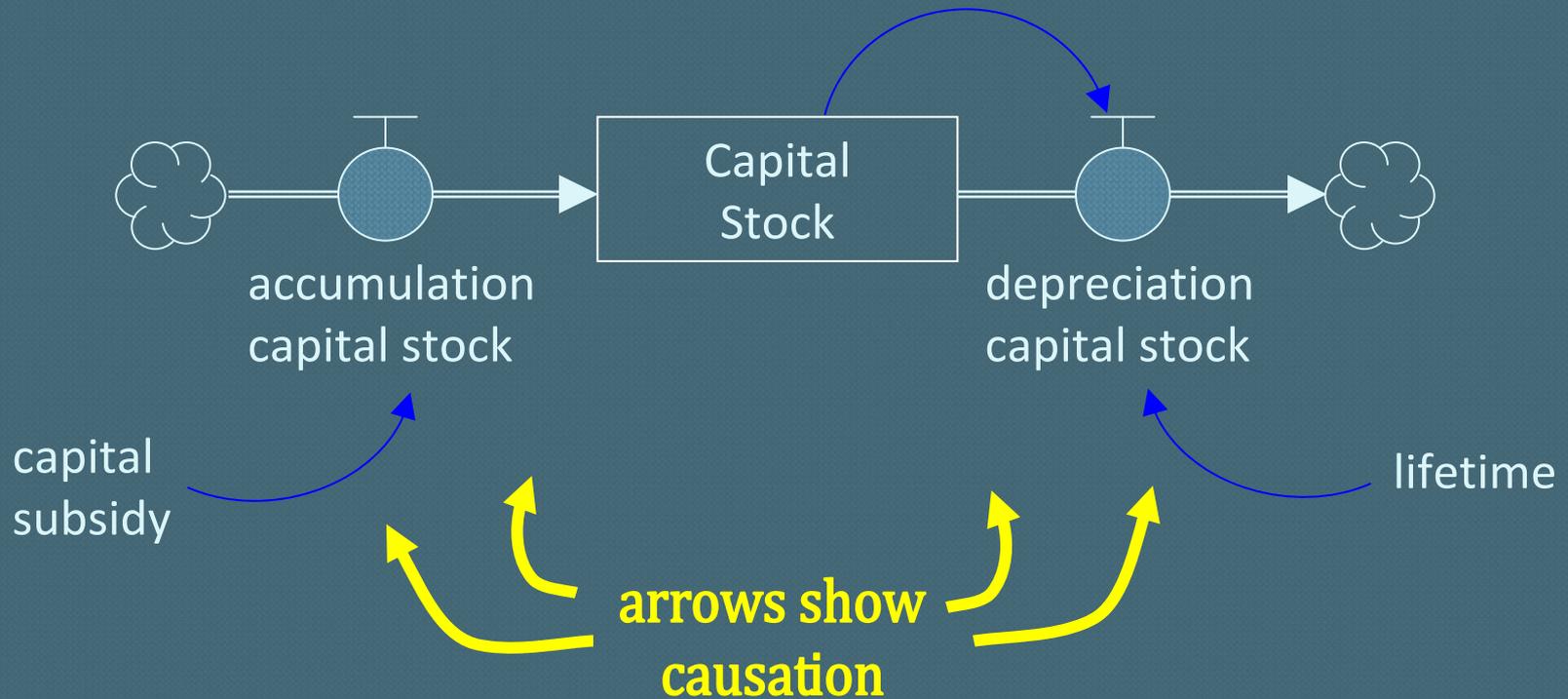
Motivation:

If we can **identify** and **characterise** the main **dynamic interactions** of the **energy-economy system** in terms of **fundamental physical laws**, then we can investigate possible **future scenarios**.

G.E.M.B.A. Model Structure

Renewable Energy Flows

Renewable Energy Sector Capital Stock

Industrial Sector Capital Stock

Non-renewable Resources

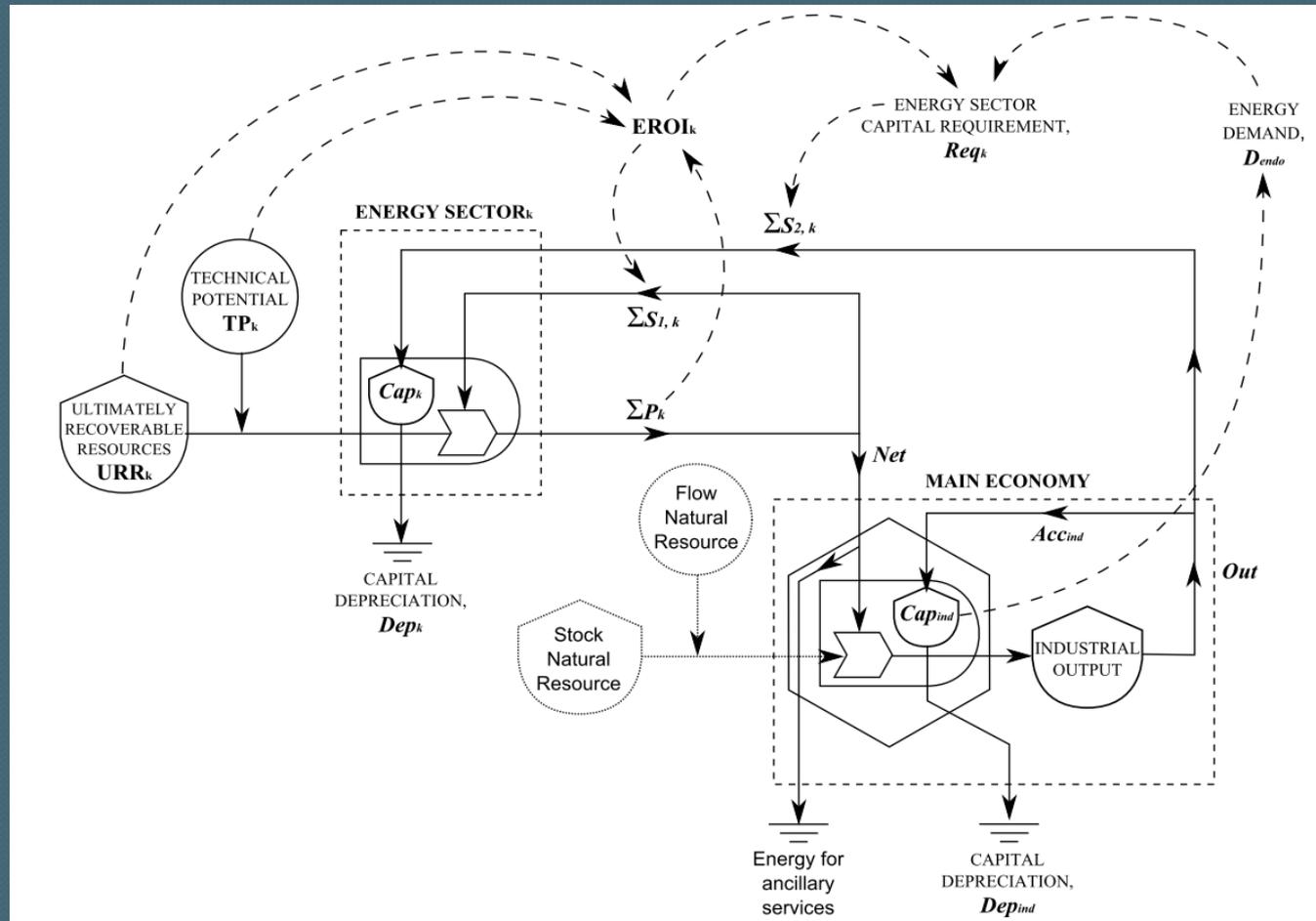Non-renewable Energy Sector Capital Stock

A Simple Model Structure:

Capital accumulation [EJ/yr] = capital subsidy [EJ/yr]
Capital depreciation [EJ/yr]= Capital Stock [EJ]/ lifetime [yrs]
Capital Stock [EJ] = ∫ (accumulation[EJ/yr]-depreciation[EJ/yr])dt

G.E.M.B.A. Model Structure (cont.):

G.E.M.B.A Model Structure:

Allocation

Non-renewable
Sector

Industrial Sector

Renewable
Sector
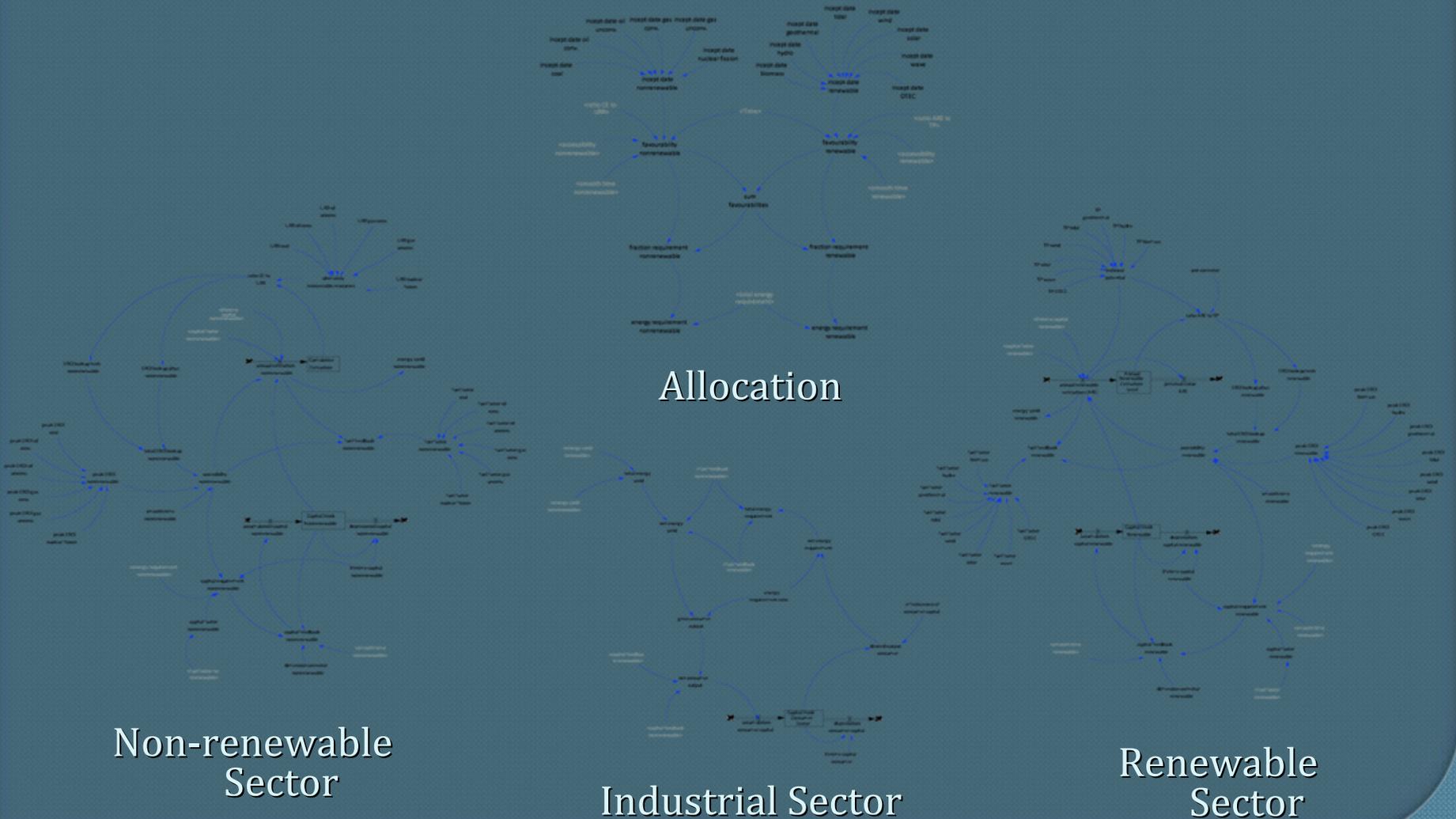
Rules of the Game:

- Each energy source is characterised by **four fundamental variables**:

  - **Incept date:** the year that the energy source first enters the market-place;
  - **Availability:** how much of the energy source is available
  - **Accessibility:** the energy-return-on-investment (EROI) offered by the energy source.
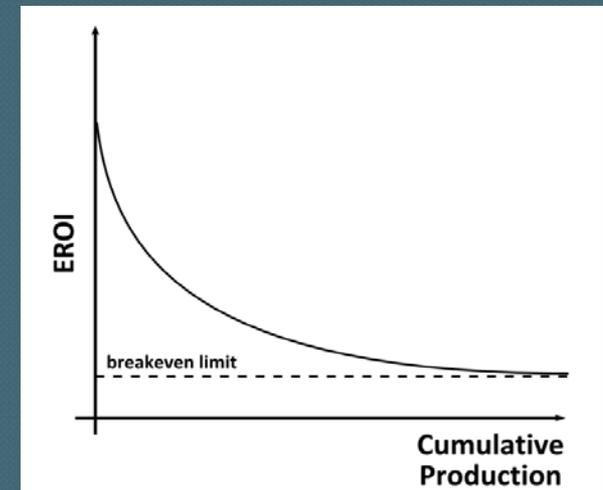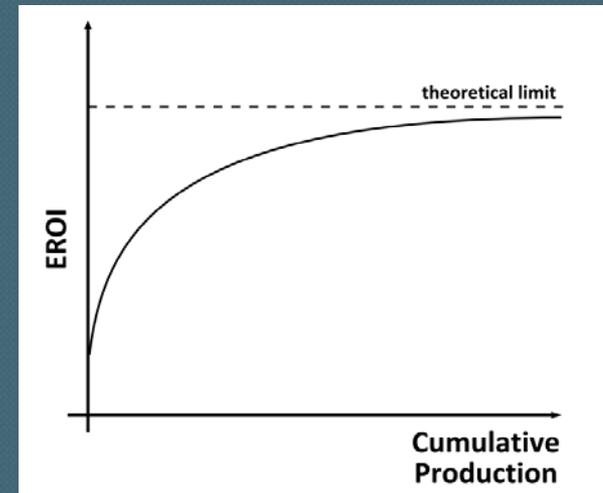 - **Capital factor:** the ratio S2 / (S1 + S2)

Accessibility:

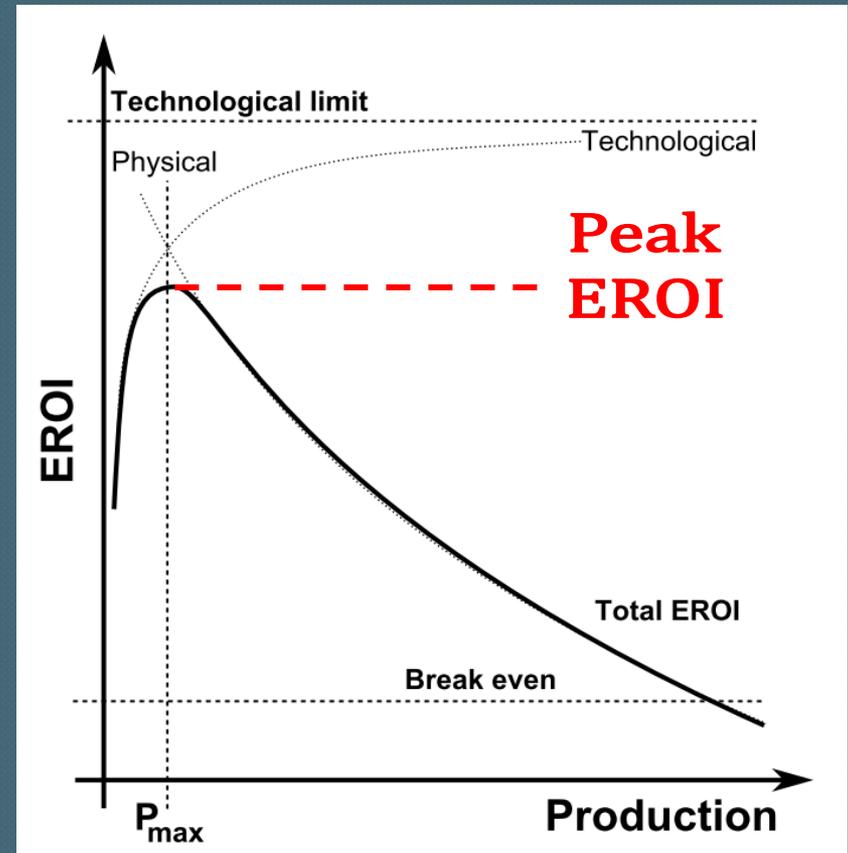- Technical progress increases EROI to some limit

$$1 - \Xi \exp^{-\xi p}$$

- Resource depletion decreases EROI

$$\Phi \exp^{-\phi p}$$

Accessibility:

- Total EROI is the product of the two functions
- EROI is a peaking function
- Is a function of the fraction of resources still available

Costanza and Cleveland(1983)

Assumptions:

- **Energy demand** is **homogenous** amongst energy sources, i.e. **energy sources** are perfectly **substitutable**

- **Capital needs** of **energy sector** takes **priority**

Energy Demand:

- Energy demand is an endogenous function of three factors:
  - Cap_{ind} = INDUSTRIAL CAPITAL STOCK, [EJ];
  - κ = CAPITAL EFFECTIVENESS, [1/yr]
  - ε = ENERGY REQUIREMENT RATIO, [dmnl]

$$Demand = \varepsilon \kappa Cap_{ind}$$

# Appendix - Link between Capital Stock & Energy Production:

- If I know the capital stock, Cap_{energy}, how can I calculate energy production?

$$EROI = \frac{total\ energy\ output}{total\ energy\ inputs} = \frac{annual\ production \times lifetime}{capital + fuel\ inputs}$$

$$\chi_{energy} = \frac{capital\ inputs}{total\ energy\ inputs} = \frac{capital\ inputs}{capital + fuel\ inputs} < 1$$

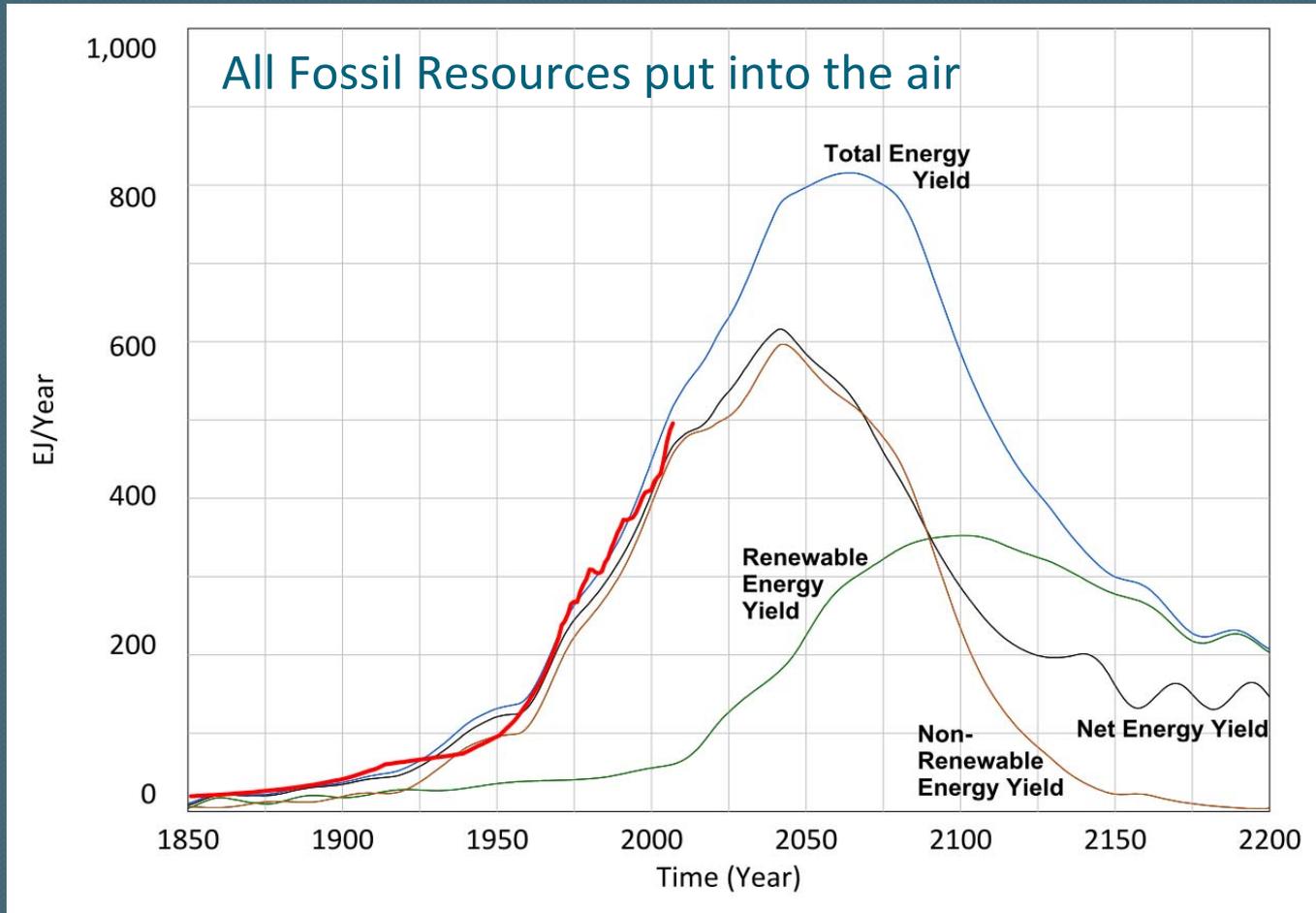$$annual\ production = P_{energy} = \frac{Cap_{energy}}{\chi_{energy}} \frac{EROI_{energy}}{lifetime}$$

Calibration – TPES
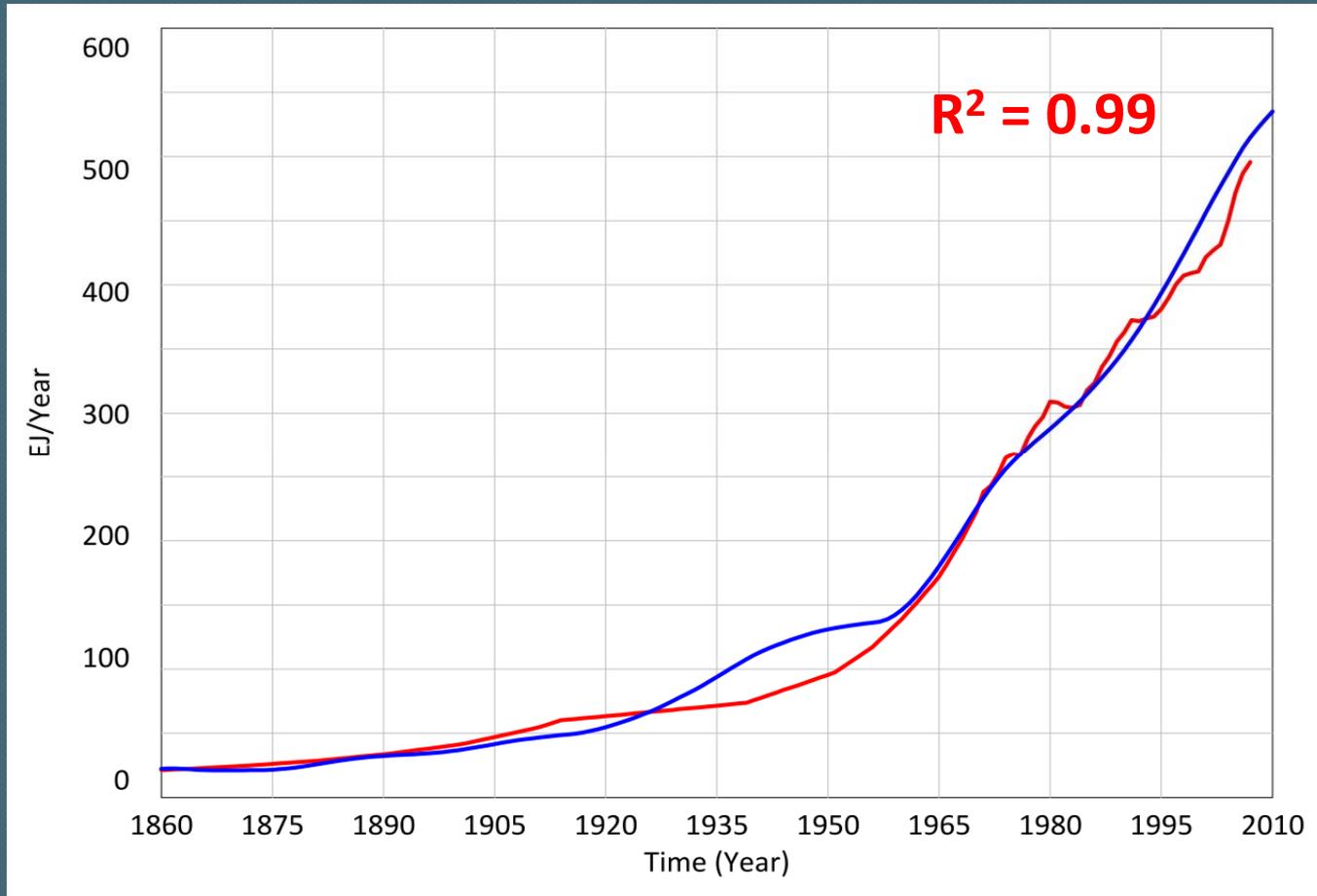
Projections into the Future:

- What happens when we let the model run beyond the present?

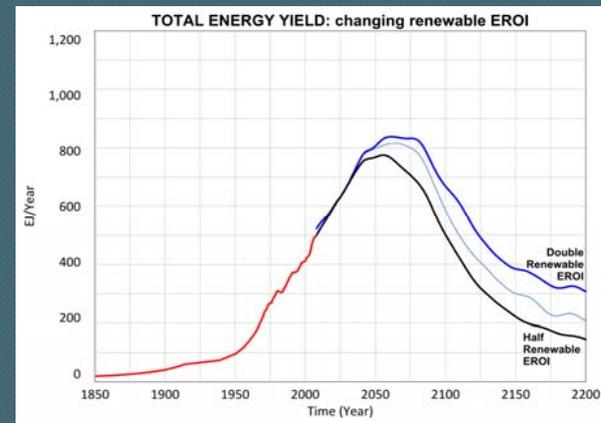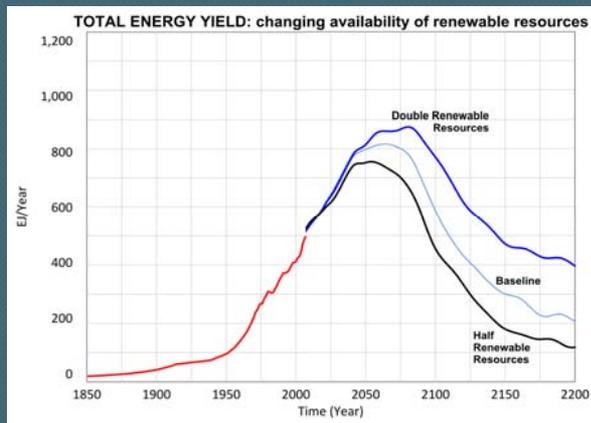- What **trends** are predicted for future energy supply?
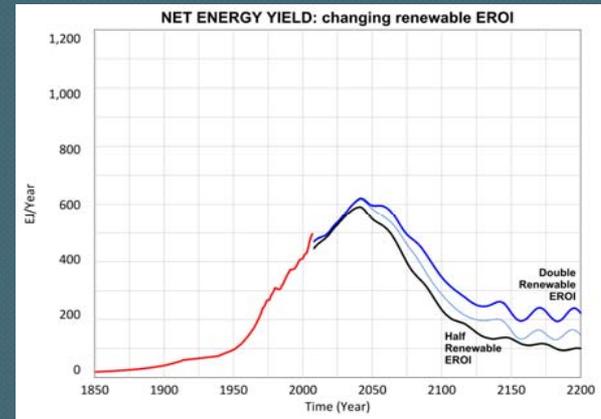
Results – baseline:

All Fossil Resources put into the air

Results – sensitivity analysis

A: Changing resource availability
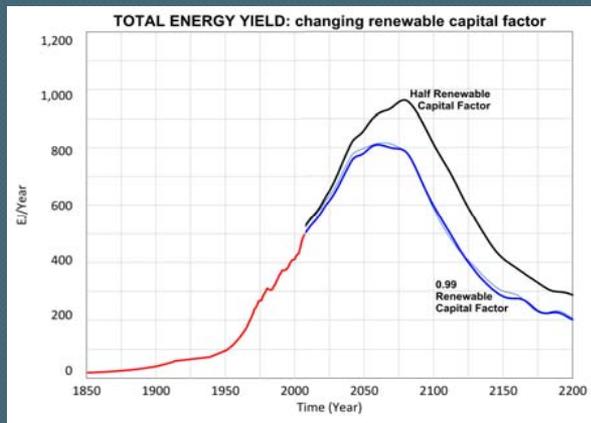
B: Changing renewable EROI
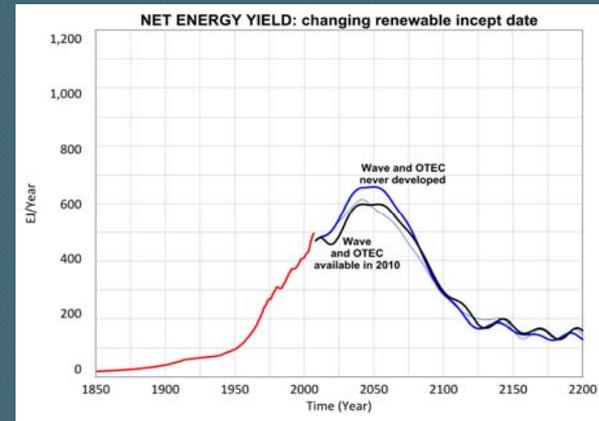
Results – sensitivity analysis

A: Changing renewable capital factor

B: Changing renewable incept date

Total Energy Yield
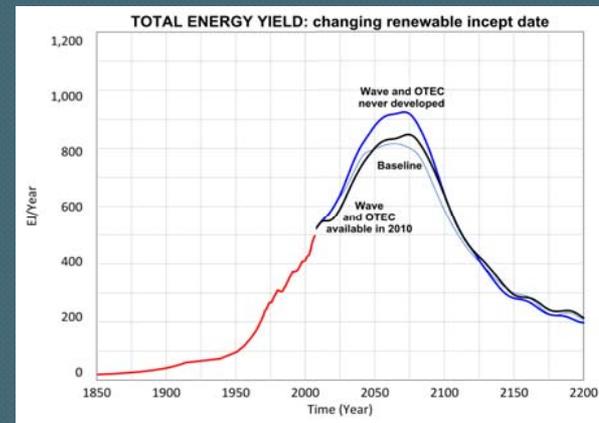
Net Energy Yield
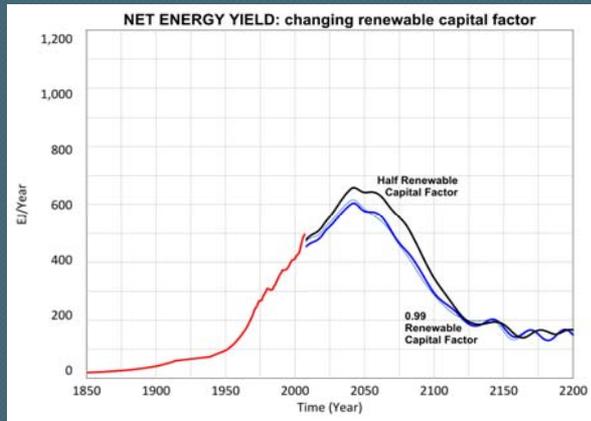
Summary of Results:

- GEMBA model displays **stability** to large changes in initial conditions.
- Despite a **doubling** in the availability of renewable energy resources over the baseline case, the TOTAL ENERGY YIELD and NET ENERGY YIELD still peaked and then declined
- **Same pattern** was repeated for changes in the EROI, and for changes in the CAPITAL FACTOR and the INCEPT DATE of renewable sources.
- In systems language the behaviour displayed is said to be **self-regulating**.

Discussion:

- The **weakest assumption** is probably that of '**perfect substitutability**' amongst the various energy sources – witness issues of peak oil on transport.

- One **solution** would be to **disaggregate demand** into end-use 'energy services':
  - However, this raises problems of how to define, say transport demand (in tonne-km or passenger-km), and compare model results with 'historic transport demand'
  - As this has not historically been defined, **circularity** ensues.

- **Perfect substitutability** offers a '**best case' scenario** for the adaptability of the energy system to changing resources. In reality, the economy is less flexible – cars cannot burn coal.

Further Work:

- Determining the **economic** and **policy implications** of the model results
- **Integration** with **existing energy models** - MESSAGE, MARKAL, NEMS
- Addition of **other modules**:
  - Pollution – e.g. CO_2
  - Population
  - Natural resources

Acknowledgements

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- Huge thanks to Prof. Pat Bodger and Dr. John Peet for their patience guidance and tremendous support .
- Thanks also to the Keith Laugesen Charitable Trust and the University of Canterbury for their financial assistance