A Biophysical Perspective of IPCC Integrated Energy Modelling

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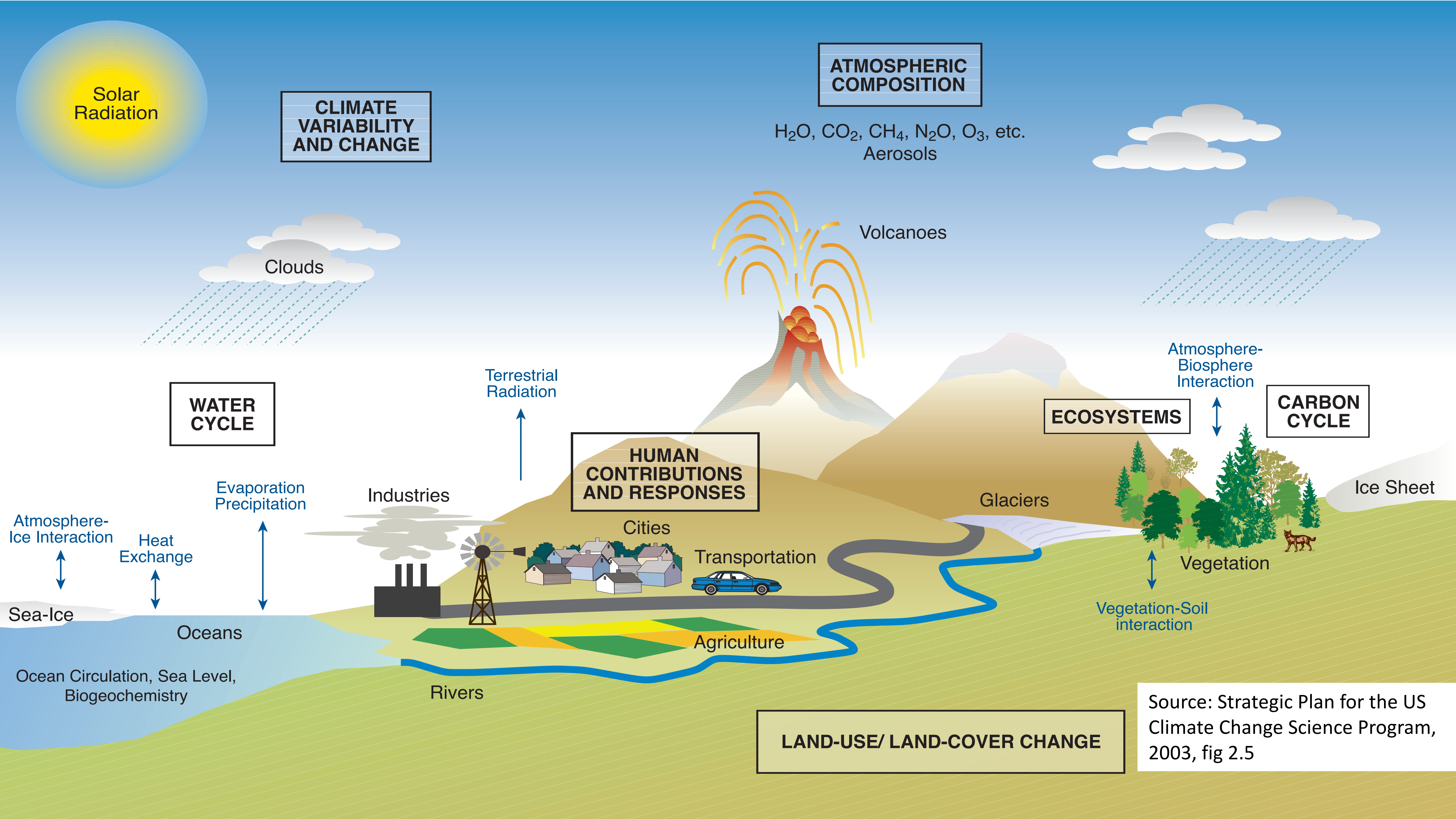
Overview

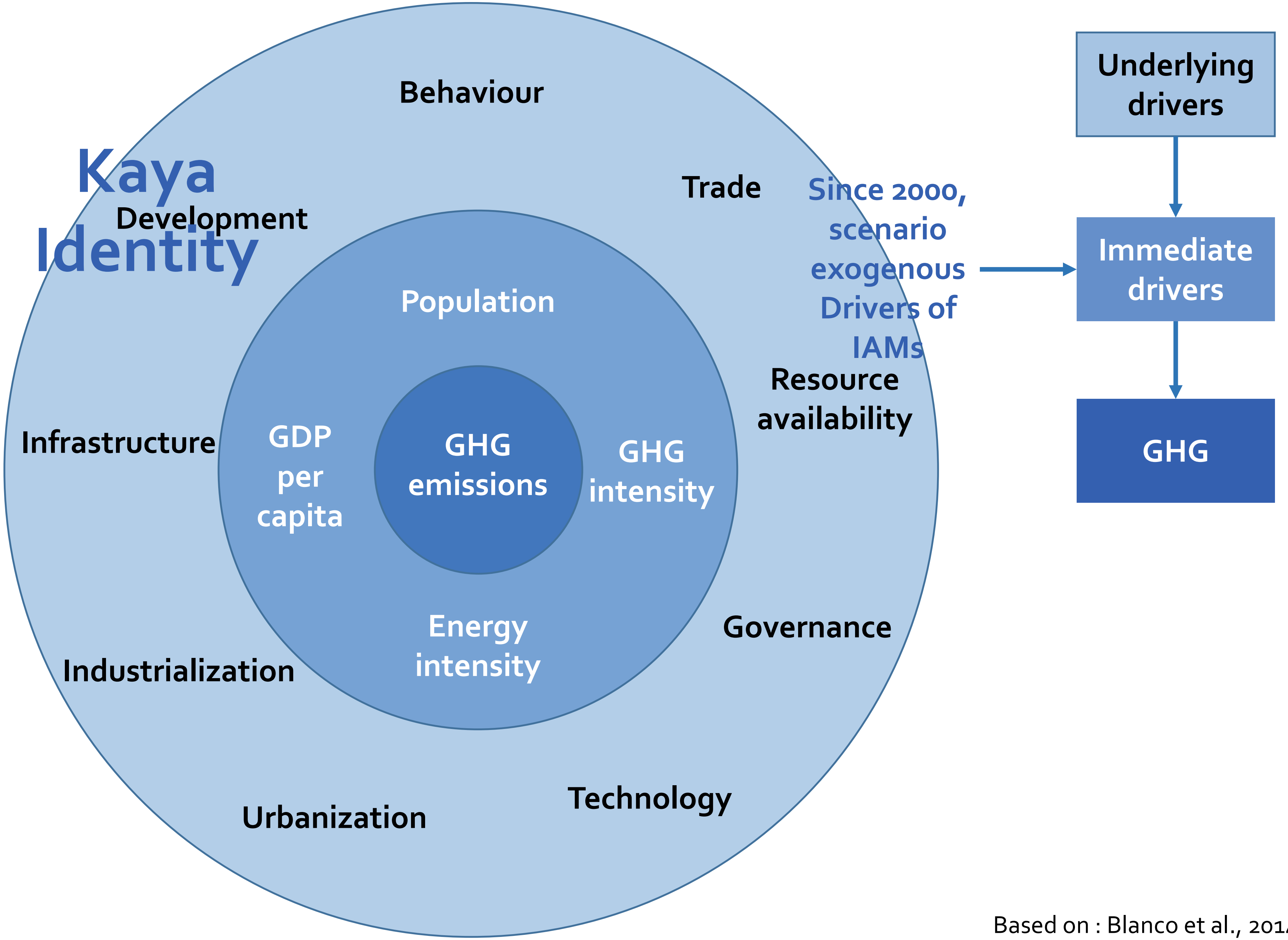
- Economic growth in Integrated assessment models (IAMs)
- KAYA identity
- A Biophysical perspective
- A proposed conceptual model
- Conclusions



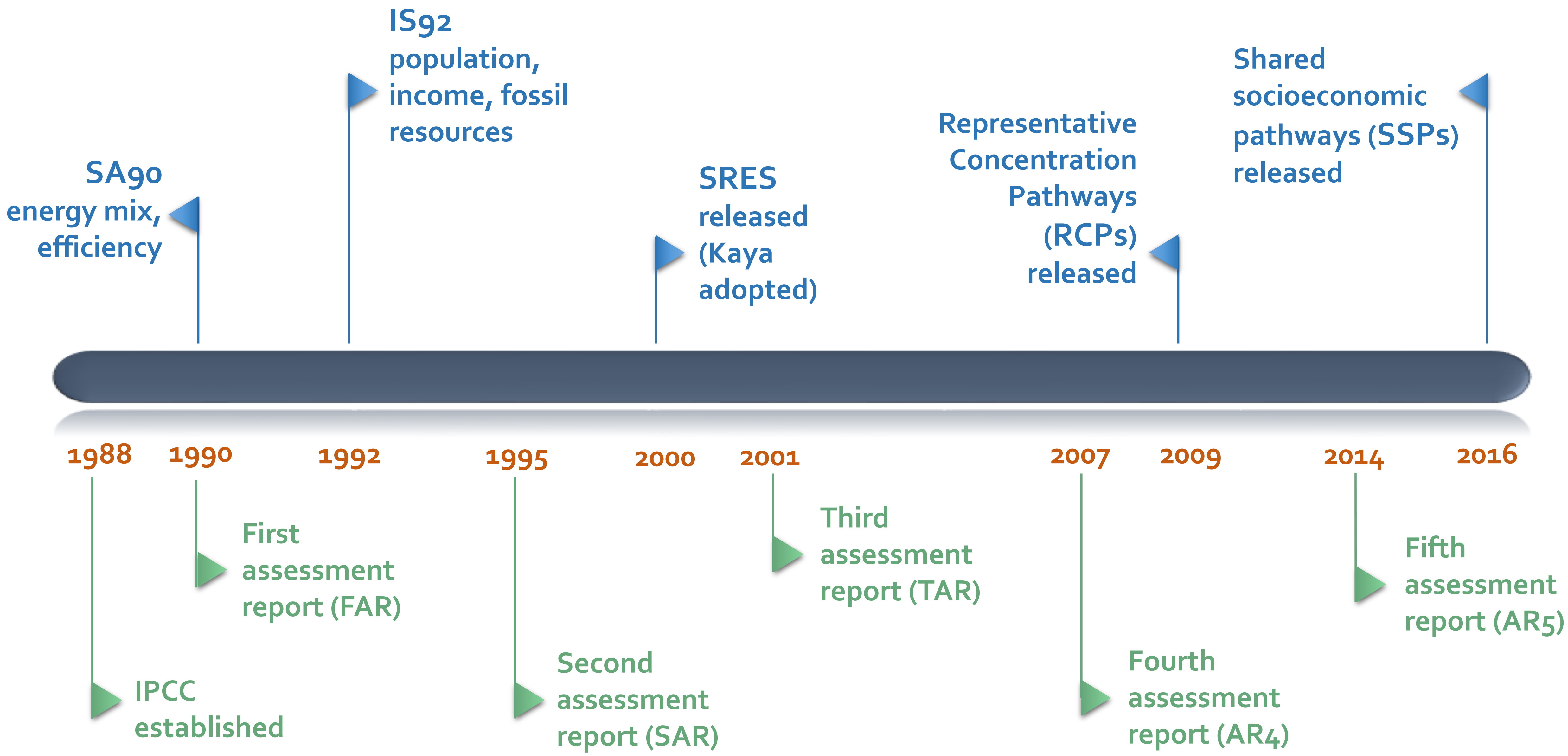
Source: Strategic Plan for the US Climate Change Science Program, 2003, fig 2.5

Integrated Assessment Models (IAMs)

- Highly simplified, stylized, numerical models
- Integrate energy, agriculture, carbon cycle and the economy
- Use economics as a basis for decision making
- IAMs are driven by exogenous scenarios



Based on : Blanco et al., 2014



IS92
population, income, fossil resources
Shared socioeconomic pathways (SSPs) released
Representative Concentration Pathways (RCPs) released
SA90
energy mix, efficiency
SRES released (Kaya adopted)
1988
1990
1992
1995
2000
2001
2007
2009
2014
2016
First assessment report (FAR)
Third assessment report (TAR)
Fifth assessment report (AR5)
Second assessment report (SAR)
Fourth assessment report (AR4)
IPCC established

Kaya identity

$$CO_2 = Population \times \frac{GDP}{Population} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$$

Wealth

Energy intensity of economic activity

Carbon intensity of energy

Kaya identity

$$CO_2 = Population \times \frac{GDP}{Population} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$$

$$Impact = Population \times Affluence \times Technology$$

(Ehrlich & Holdren)

- ***Identities versus formulas***
- ***Equation versus stylized depiction***
- ***Dependencies***
- ***Descriptive equations***

Kaya identity

$$CO_2 = \text{Population} \times \frac{\text{GDP}}{\text{Population}} \times \frac{\text{Energy}}{\text{GDP}} \times \frac{CO_2}{\text{Energy}}$$

$$CO_2 = \text{Population} \times \frac{\text{Energy}}{\text{Population}} \times \frac{CO_2}{\text{Energy}}$$

- *Kaya is a mathematical identity*
- *Does not describe a causal relationship*
- *Right hand side terms are not independent*
- *These issues are explicitly identified in the scenario literature (e.g SRES 2000)*
- *Useful decomposition tool*
- *Best understood at a macro level*

The power of Kaya is that it supports a techo-optimist framing ...

$$CO_2 = Population \times \frac{GDP}{Population} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$$

Wealth is compatible with abatement ..... (→ $\frac{GDP}{Population}$)

... if carbon intensity asymptotes towards zero (→ $\frac{CO_2}{Energy}$)

... leading to oversimplified decarbonization plans ...

$$CO_2 = Population \times \frac{GDP}{Population} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$$

Wealth rises spontaneously

Energy efficiency

Renewable energy

We just need more technology to lower CO2

Can also be expressed as percent change

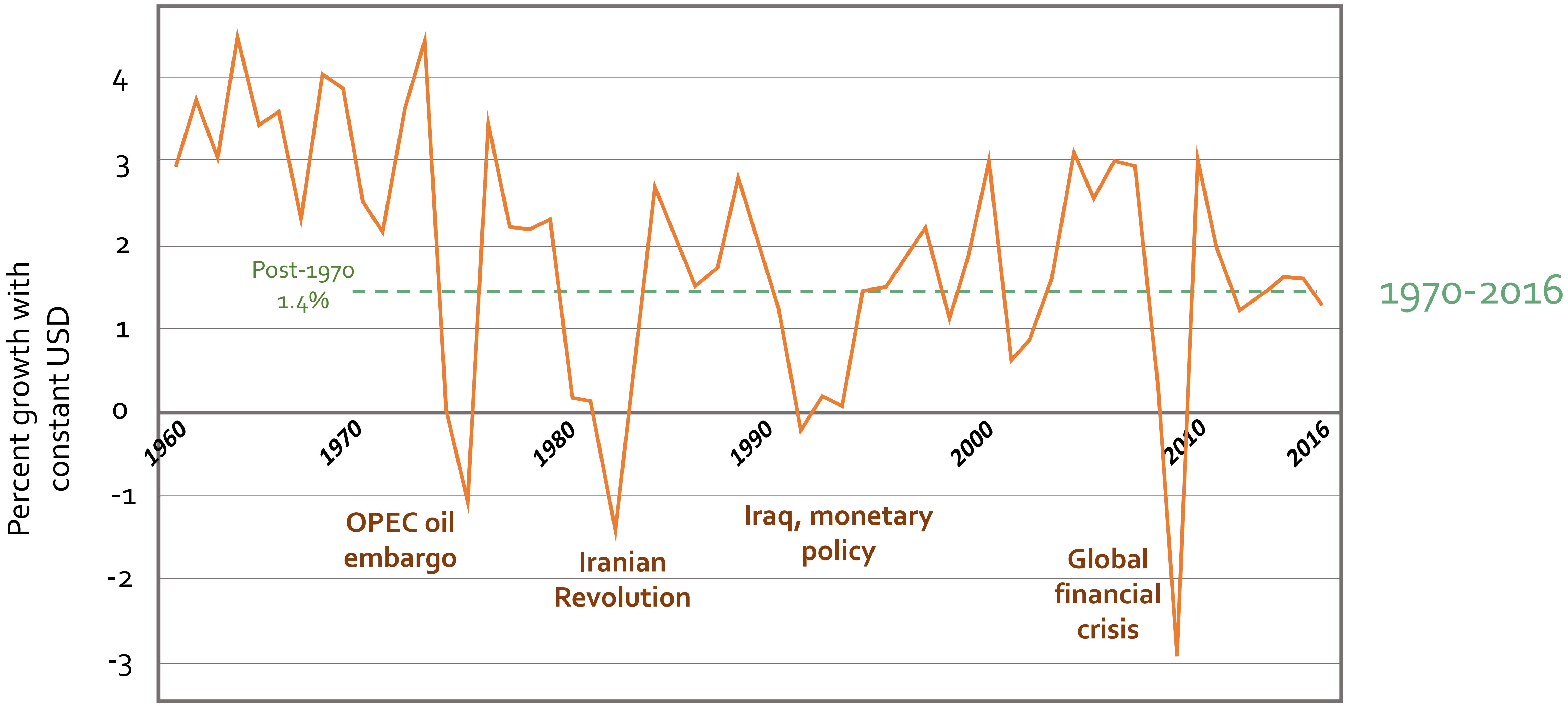
$$CO_2 = Population \times \frac{GDP}{Population} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$$

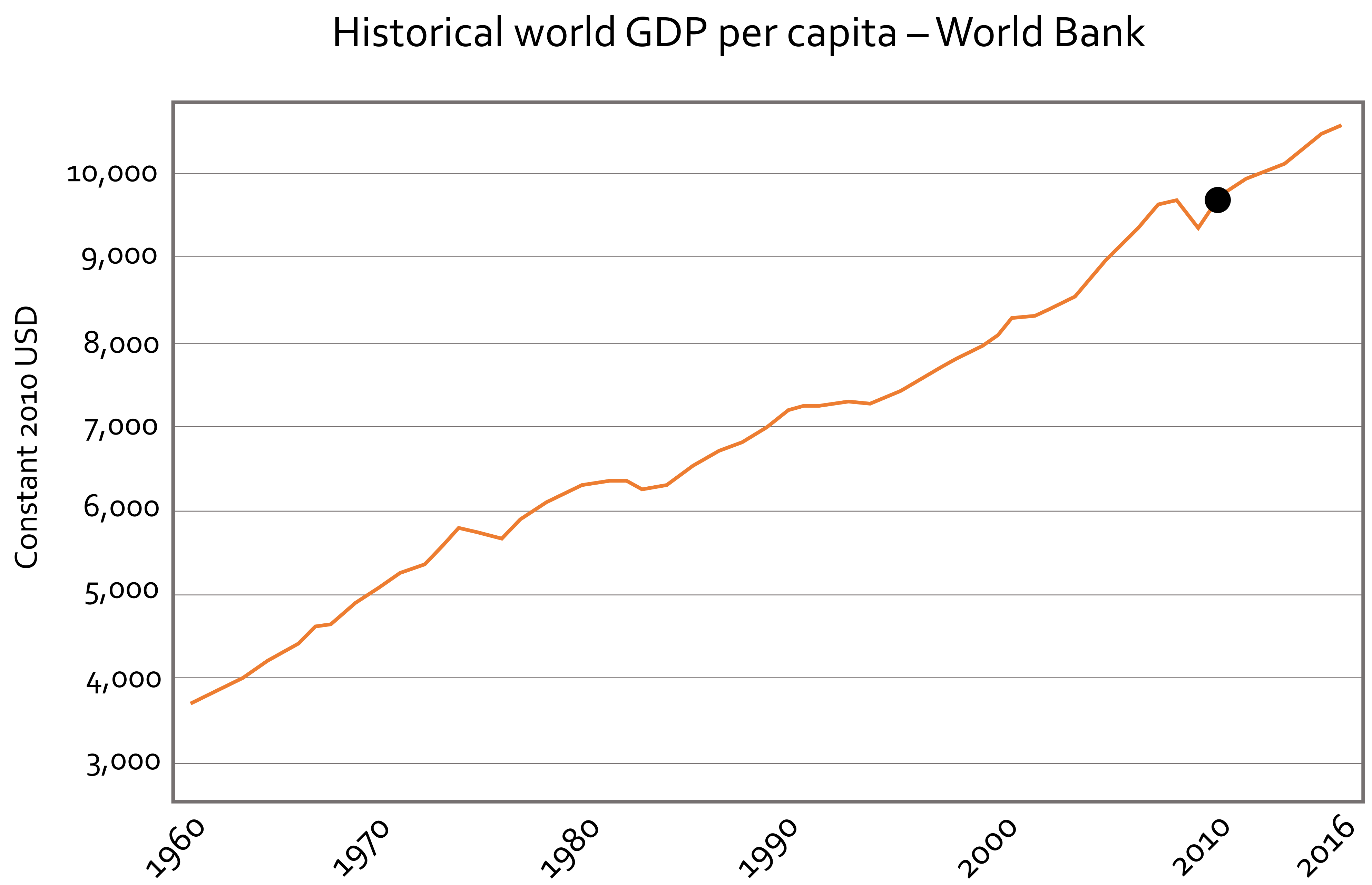
$$\underset{\Delta \to 0}{\Delta CO_2 \approx} \Delta Population + \Delta \frac{GDP}{Population} + \Delta \frac{Energy}{GDP} + \Delta \frac{CO_2}{Energy}$$

Global annual average 1970-2016

2.0% ≈ 1.5% + 1.4% + -0.8% + -0.3%

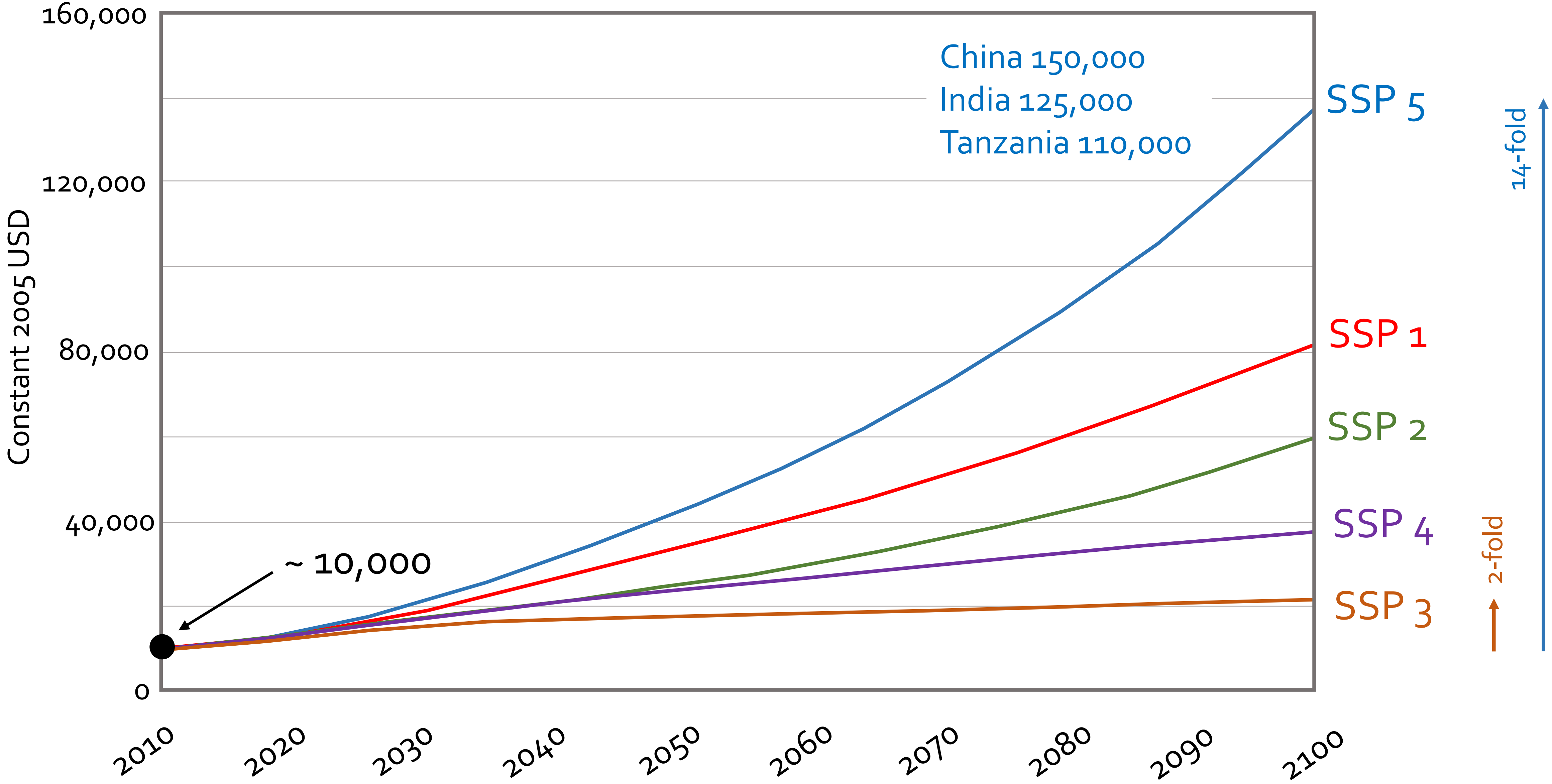
Historical change in world GDP per capita – World Bank



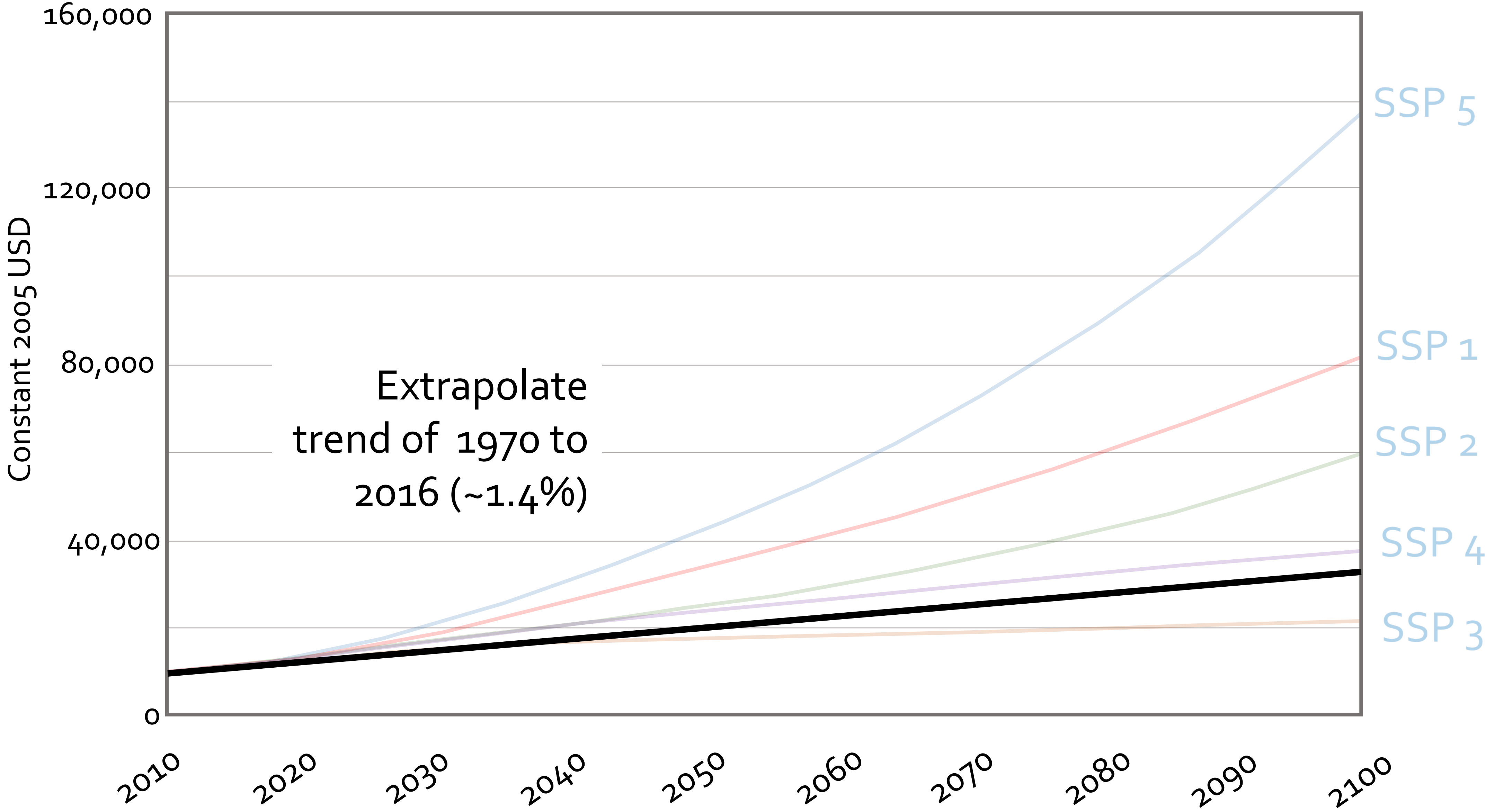


Historical world GDP per capita – World Bank
Constant 2010 USD
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
1960
1970
1980
1990
2000
2010
2016

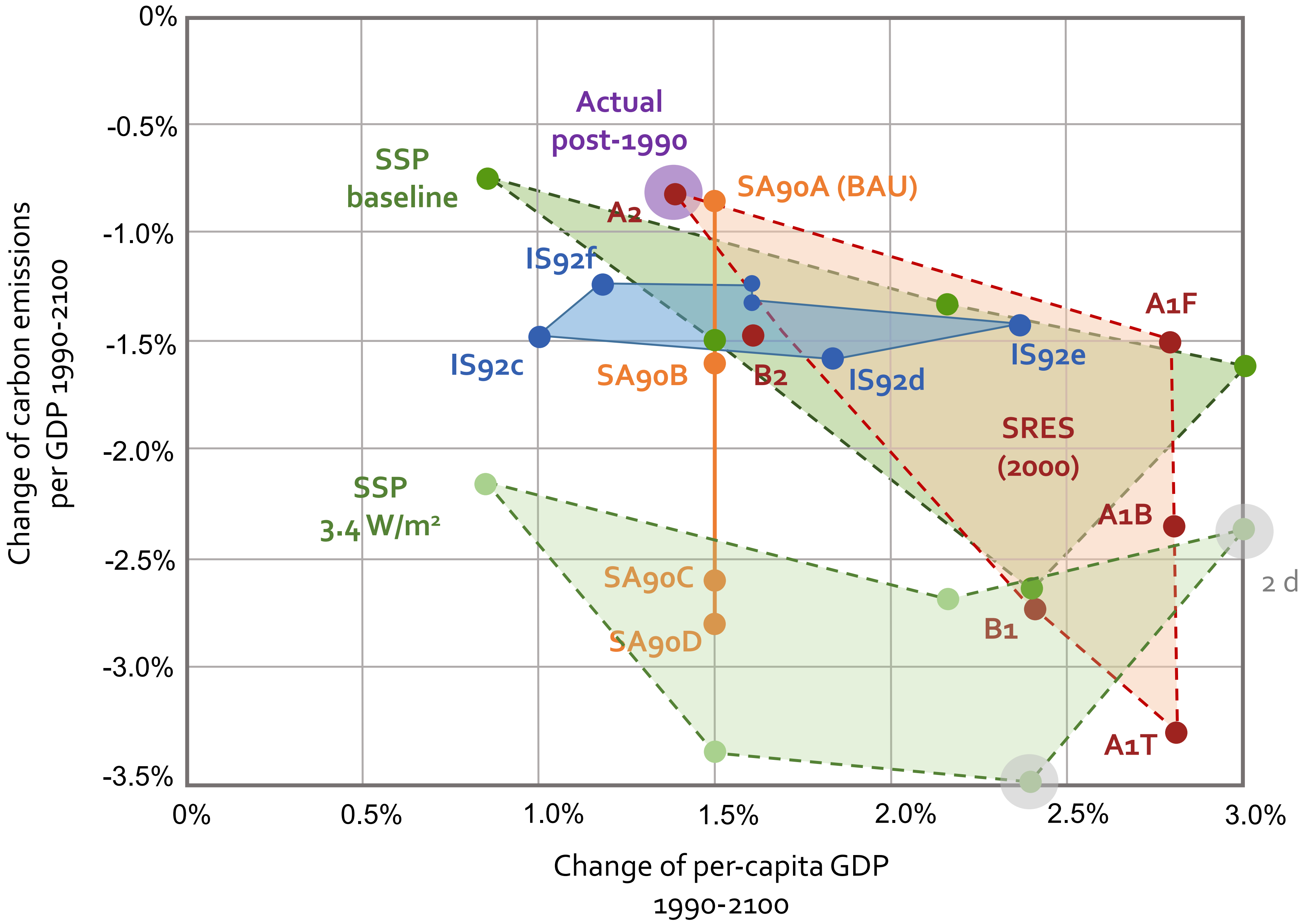
SSP scenario world GDP per capita (2005 USD) – Dellink et al. 2015



SSP scenario world GDP per capita (2005 USD) – Dellink et al. 2015



SA90, IS92, SRES, SSP scenarios - carbon intensity and income



- Y-axis combines 2 Kaya terms
- Change in carbon intensity of energy ~ 0% since 1990
- Per-capita GDP growth has been at lower end of projections

Based on Girod et al. 2008

Scenario drivers of GDP per capita growth

Labour utilization

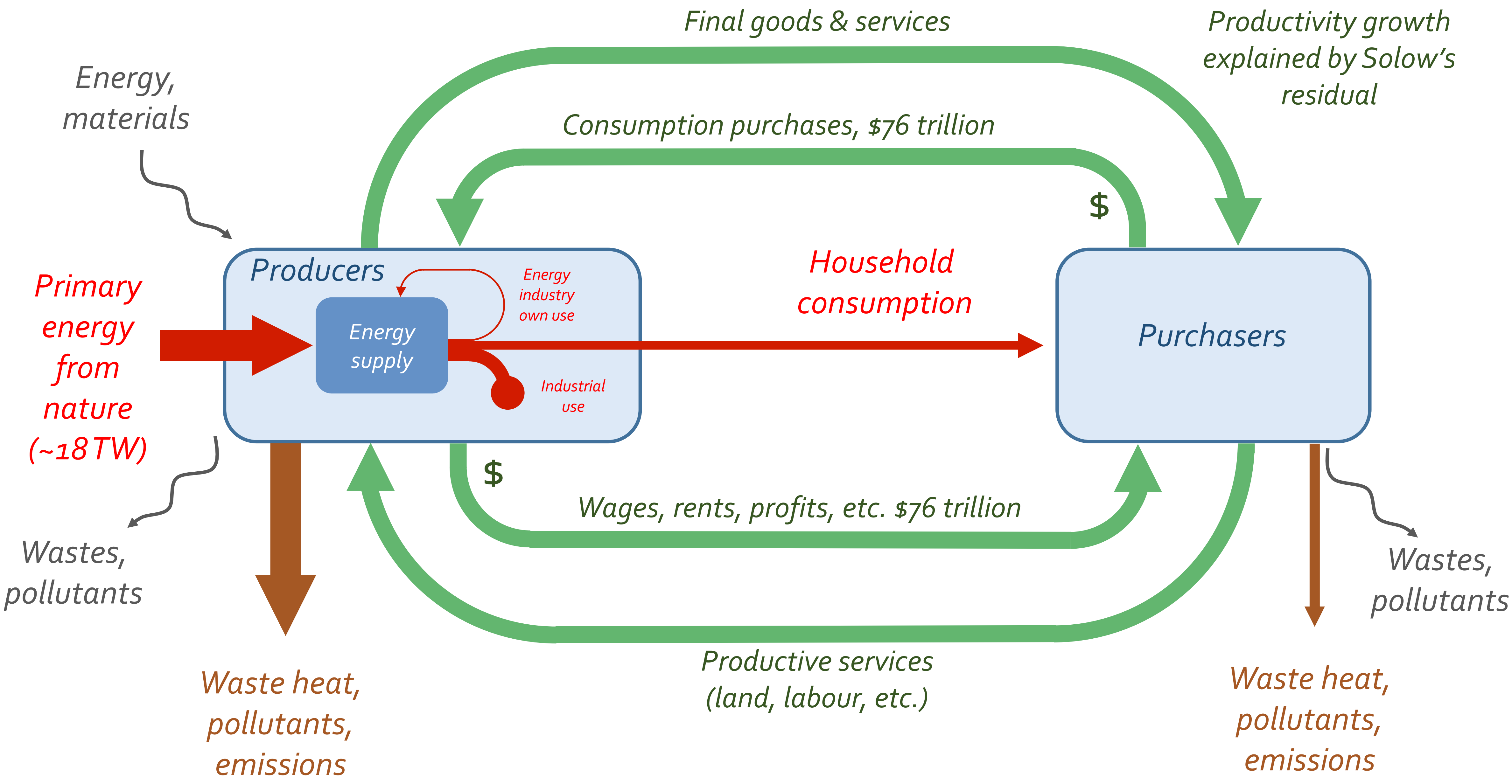
- Demographics
- Labour participation

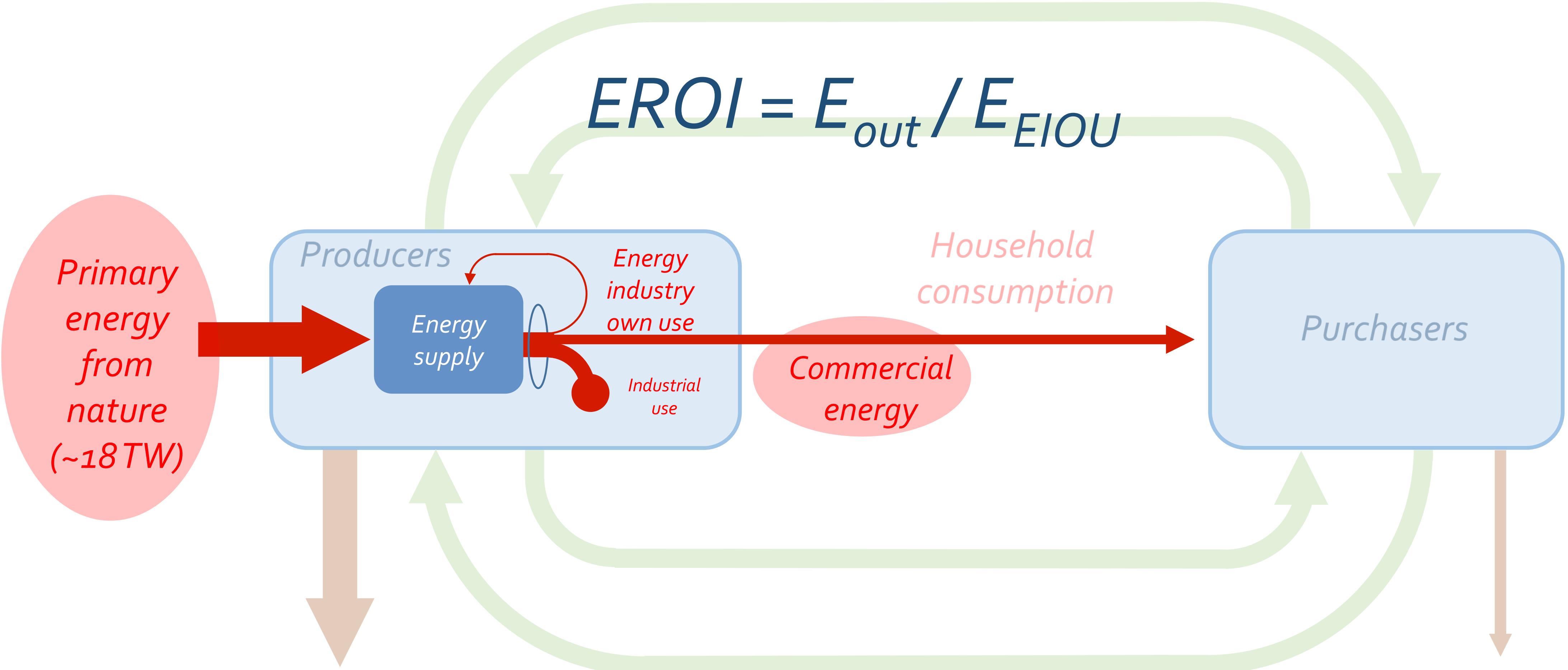
Multi-factor productivity (MFP) growth

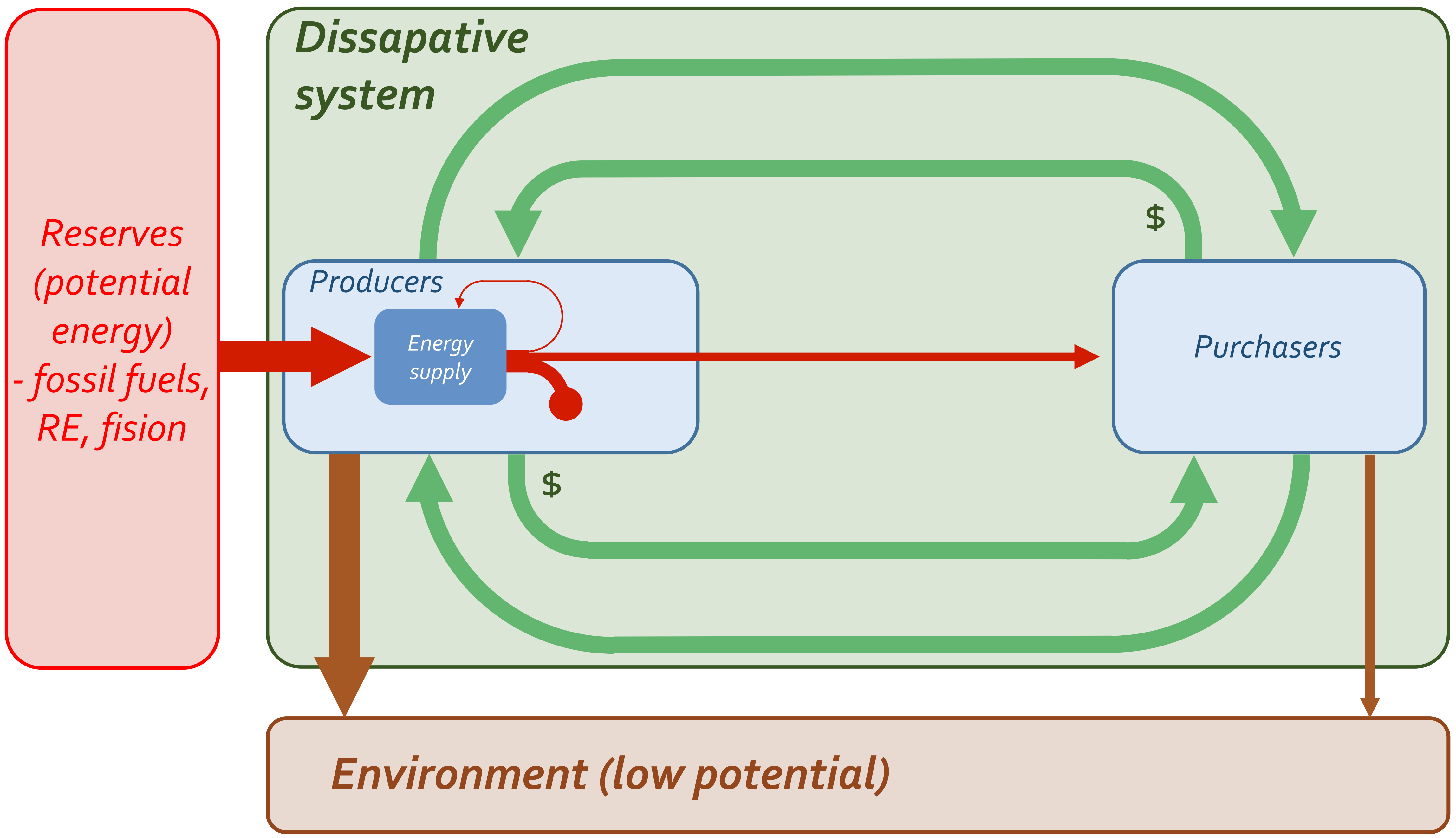
- Labour quality (human capital, education)
- Capital quality
- **Pure technical progress**

Political

- Developing country convergence

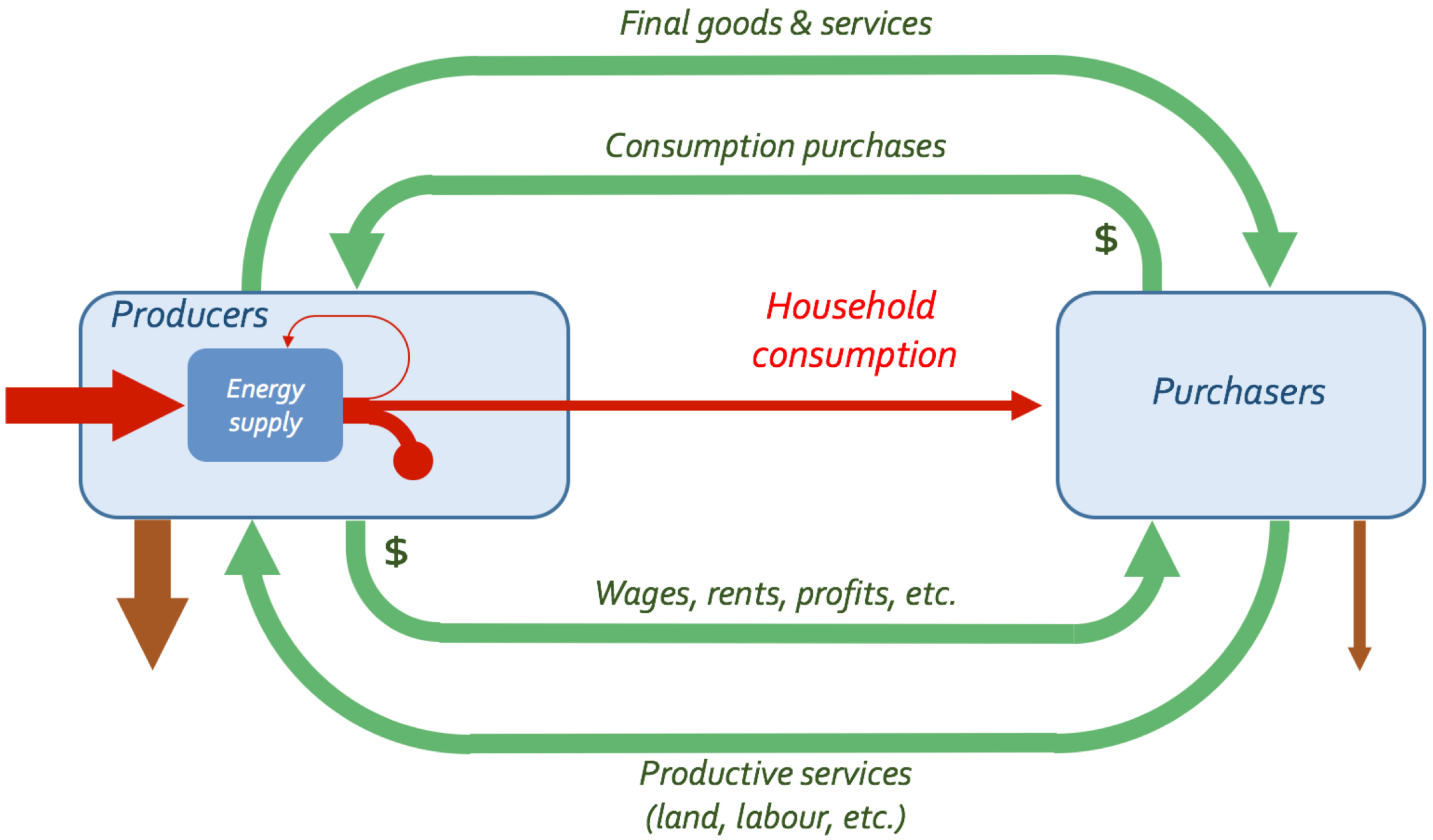

Final goods & services
Productivity growth explained by Solow's residual
Energy, materials
Consumption purchases, $76 trillion
$
Producers
Energy industry own use
Energy supply
Industrial use
Primary energy from nature (~18 TW)
Household consumption
Purchasers
$
Wages, rents, profits, etc. $76 trillion
Wastes, pollutants
Wastes, pollutants
Productive services (land, labour, etc.)
Waste heat, pollutants, emissions
Waste heat, pollutants, emissions


EROI = E_out / E_EIOU
Producers
Energy supply
Energy industry own use
Industrial use
Household consumption
Commercial energy
Purchasers
Primary energy from nature (~18TW)

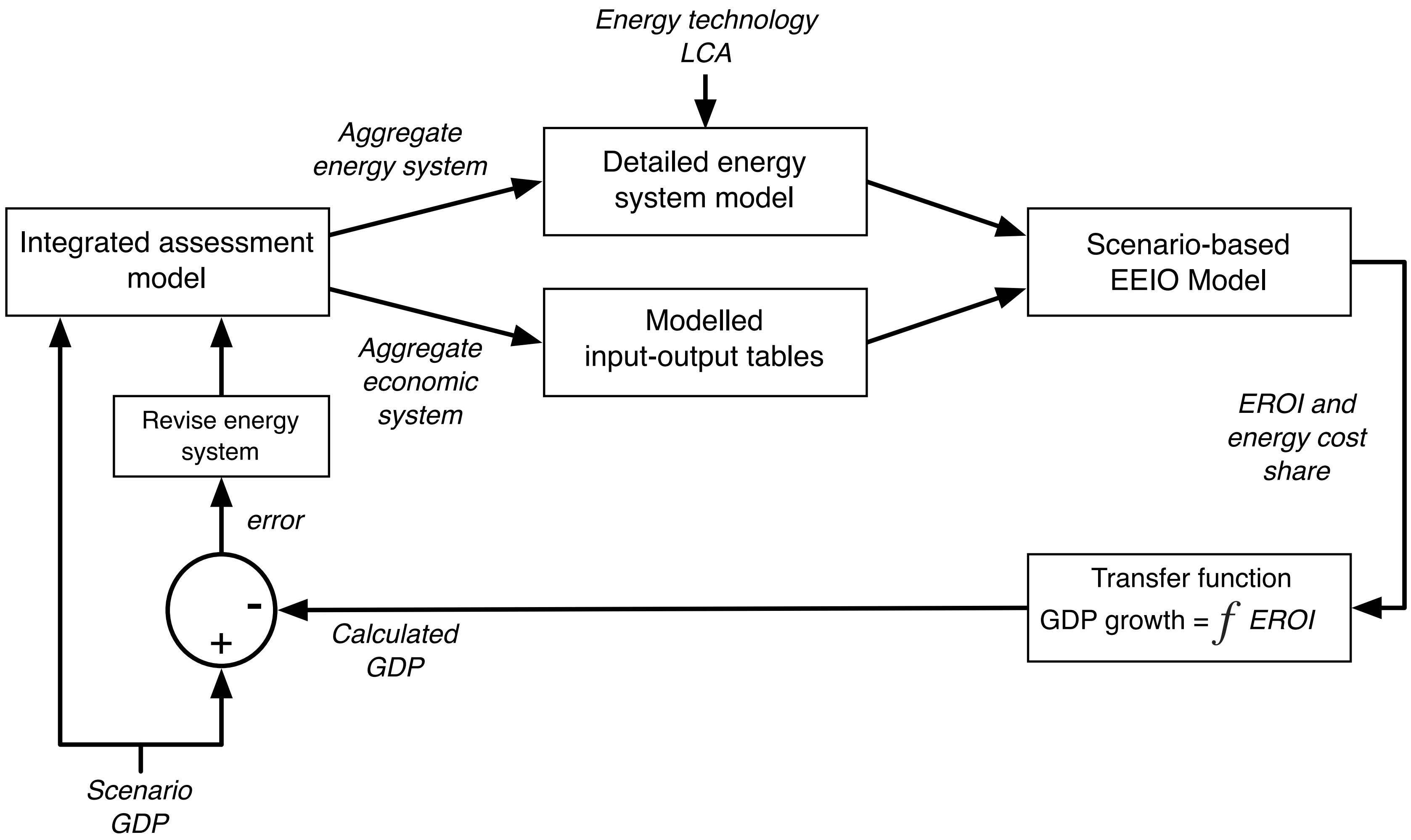


Reserves (potential energy) - fossil fuels, RE, fision
Dissapative system
Producers
Energy supply
Purchasers
$
$
Environment (low potential)

- Circular versus linear system
- Closed versus open system
- Equilibrium versus disequilibrium
- Technical progress versus energy quality
- Economic growth is an emergent property
- Can only be understood at a macro scale
- Globally, $76 trillion is sustained by 18 TW of power flows



Proposed conceptual model



From: Palmer (2018)

Kaya and standard economic assumptions in IAMs lead to a biased framing of energy transitions

The BPE perspective is that productivity and economic growth are emergent properties of the energy-economic system

The standard economic modelling approach (adopted in IAMs) does not capture the energy-economic nexus

But, BPE needs a consistent suite of tools to explain the energy-economic nexus

Conclusions

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