SCIENCE POLICY RESEARCH UNIT

Energy and Economic Growth: Learning from past transitions

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Outline

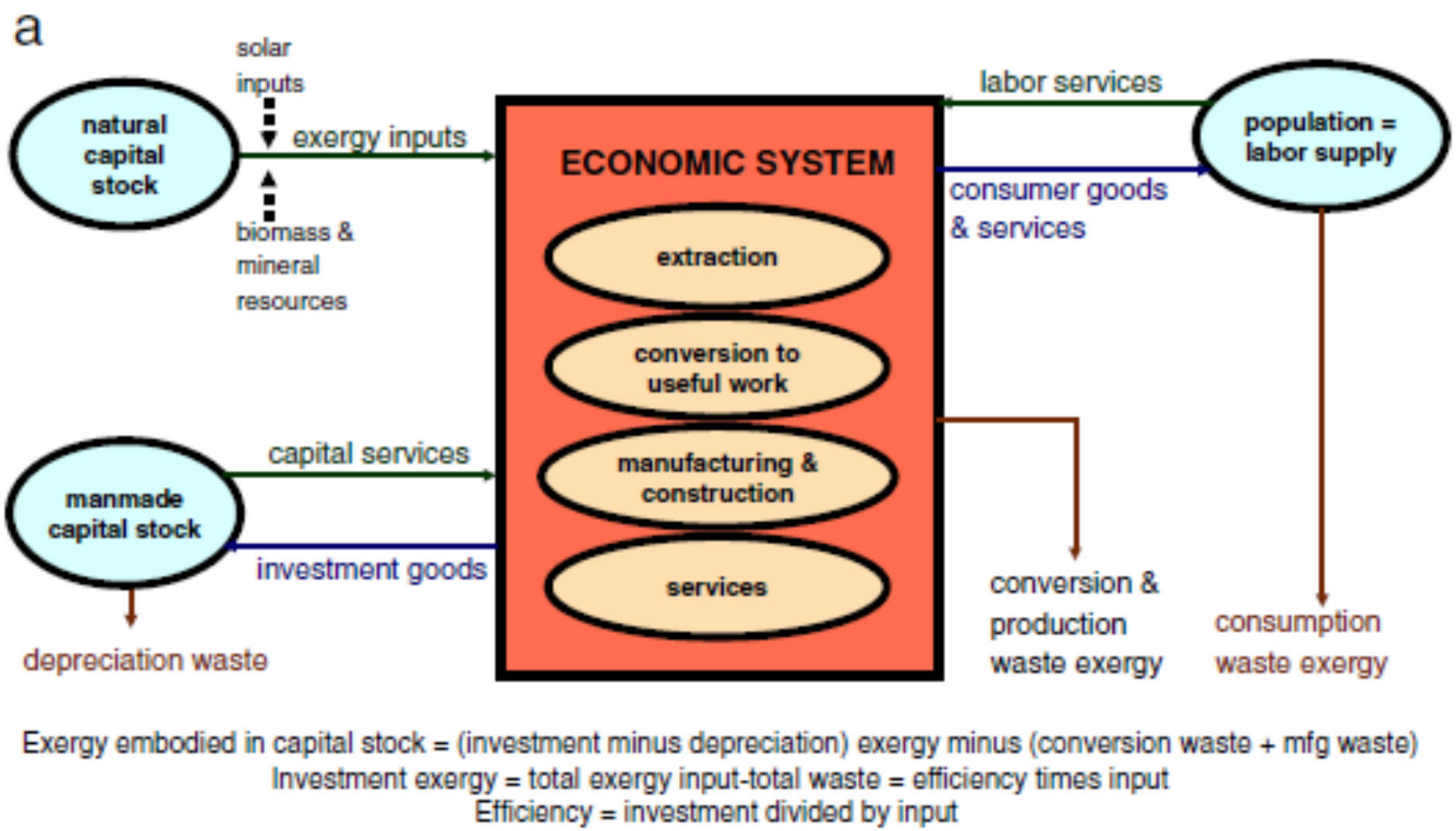
1. Challenges for UK energy policy and industrial strategy:
   - Meeting legally-binding carbon reduction targets
   - Maintaining security of supply
   - Ensuring affordability of energy services for households and businesses
   - Securing industrial opportunities for UK economy of energy innovation
2. Energy dependence of economic growth:
   - Dependence of economic growth on efficient conversion of energy sources to provide useful work
   - Role of energy technologies in past surges of economic growth
   - Importance of net energy (EROI) to economic growth
3. Insights from past great surges:
   - First Industrial Revolution
   - Post-1945 surge and consumer boom
4. Implications for policy-relevant analysis

(Draws on Foxon (forthcoming), *Energy and Economic Growth*, Routledge)

Challenges for UK energy policy and industrial strategy

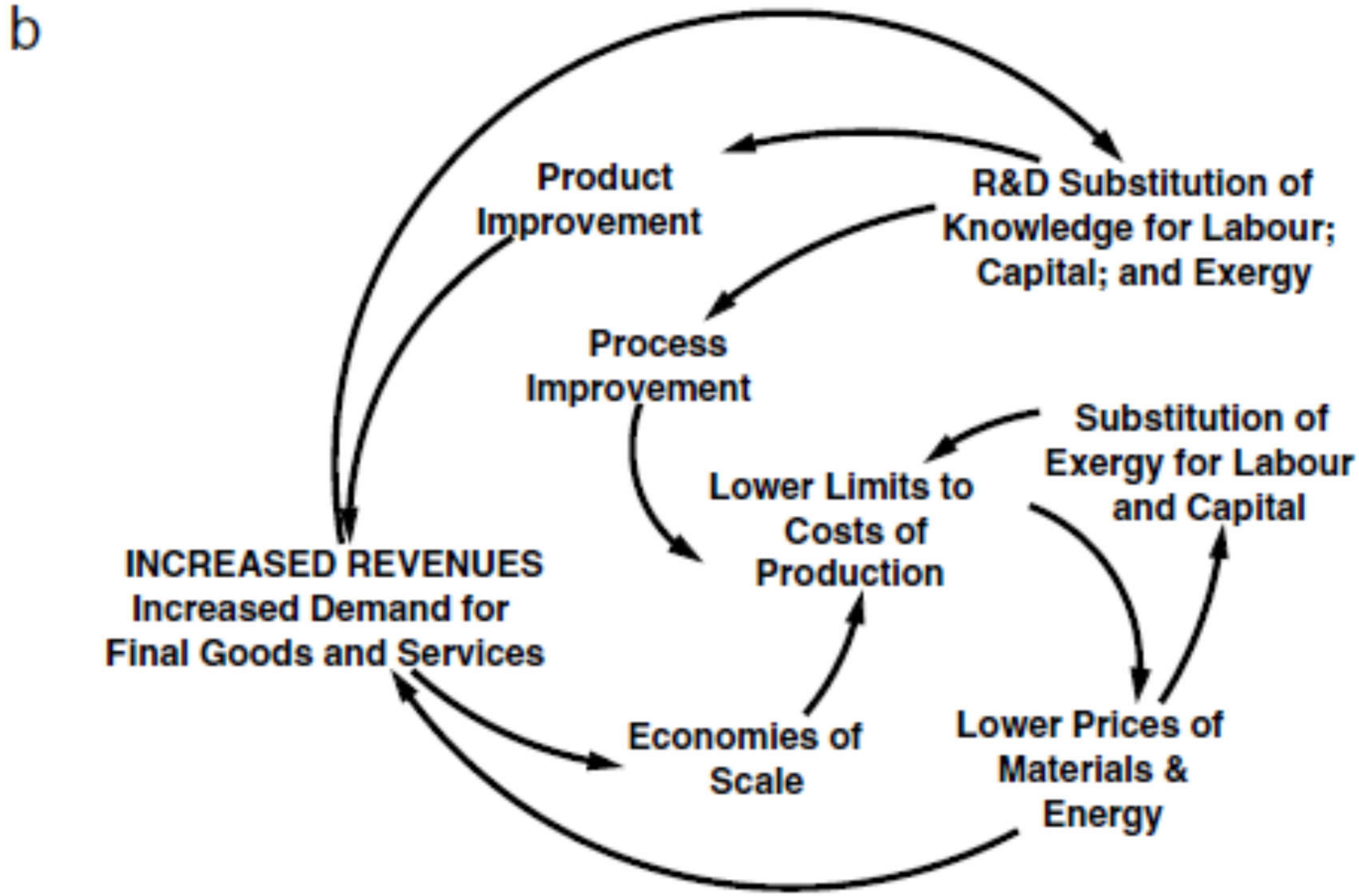
- Climate change mitigation goals under Climate Change Act:
  - 57% reduction (on 1990 levels) by 2028-32; 80% reduction by 2050
- Security of supply:
  - Declining oil and gas from North Sea
  - Increasing electrification – rapid expansion of renewables; new nuclear power but takes 10 years to build; CCS demonstration funding cut
  - Needs smart grid for local generation and demand response
- Affordability
  - 57% increase in household energy bills 2007-14; gas bills now coming down
- Industrial goals
  - Can large investments in energy innovation and infrastructure deliver significant jobs and economic benefits to UK economy?
  - What is right balance of private investment and public support?

Economy as an exergy processing system



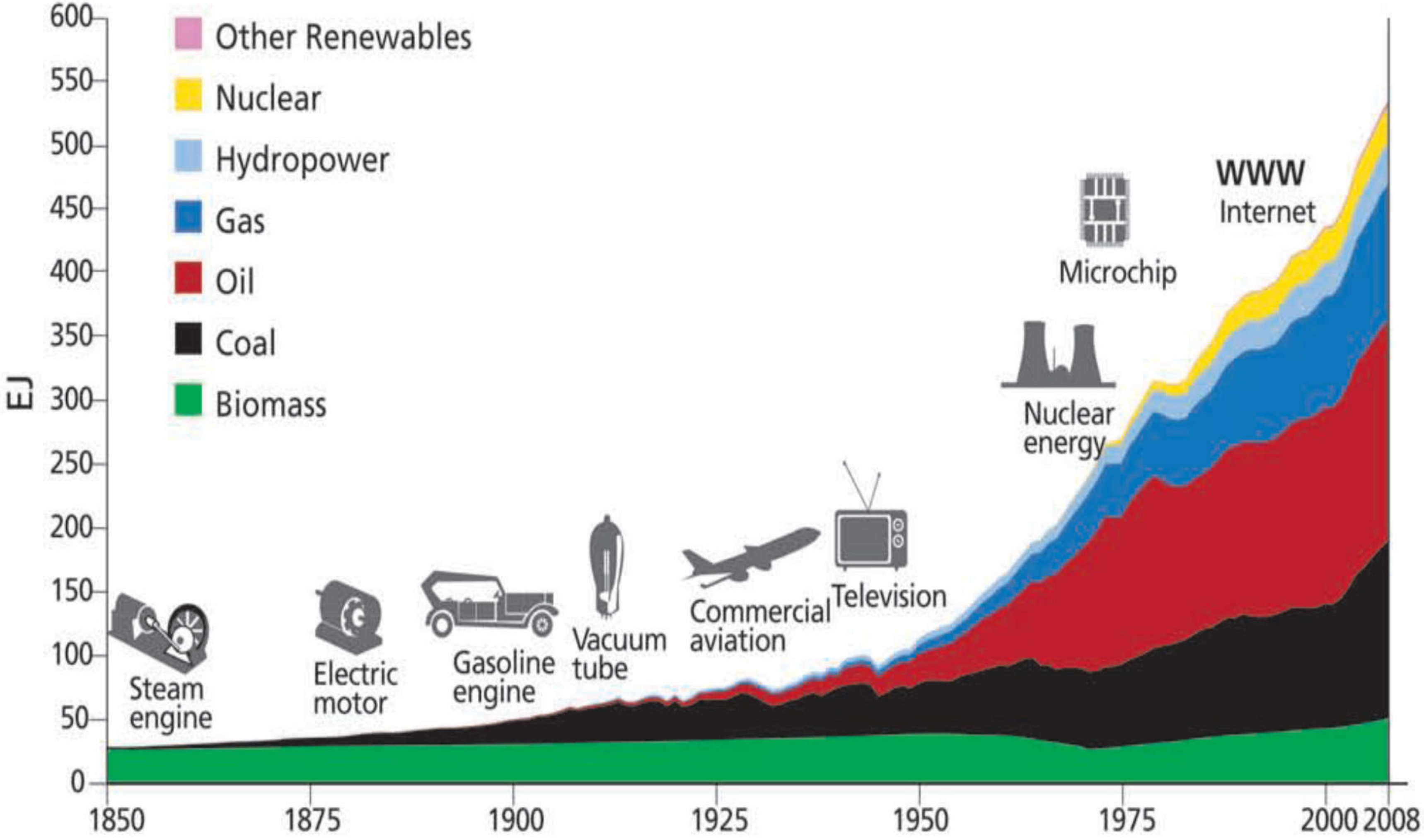
Source: Ayres and Warr (2012), in *Ecological Economics*

Substitution of exergy as an engine of growth



Source: Ayres and Warr (2012), in *Ecological Economics*

World Primary Energy Use, 1850-2008



Source: Global Energy Assessment (2012)

Five great techno-economic surges

	INSTALLATION PERIOD	TURNING POINT	DEPLOYMENT PERIOD	
No., date, revolution, core country	'Gilded Age' Bubbles	Recessions	'Golden Ages'	Maturity/decline
1st 1771 The Industrial Revolution Britain	Canal mania UK	1793–97	Great British leap	
2nd 1829 Age of Steam and Railways Britain	Railway mania UK	1848–50	The Victorian Boom	
3rd 1875 Age of Steel and heavy Engineering Britain / USA Germany	London funded global market infrastructure build-up (Argentina, Australia, USA)	1890–95	Belle Époque (Europe)(*) 'Progressive Era' (USA)	
4th 1908 Age of Oil, Autos and Mass Production / USA	The roaring twenties USA Autos, housing, radio, aviation, electricity	Europe 1929–33 USA 1929–43	Post-war Golden age	
5th 1971 The ICT Revolution USA	Internet mania, Telecoms 1990s emerging markets Global financial casino&housing 2000s	2000-03 / 2008-20??	**Global sustainable 'golden age'?**	

We are here (↑ 2008-20??)

(*) Note an overlap of more than a decade between Deployment 3 and Installation 4

Source: Perez (2016), in *Jacobs and Mazzucato*

1st and 2nd surges (Industrial revolution)

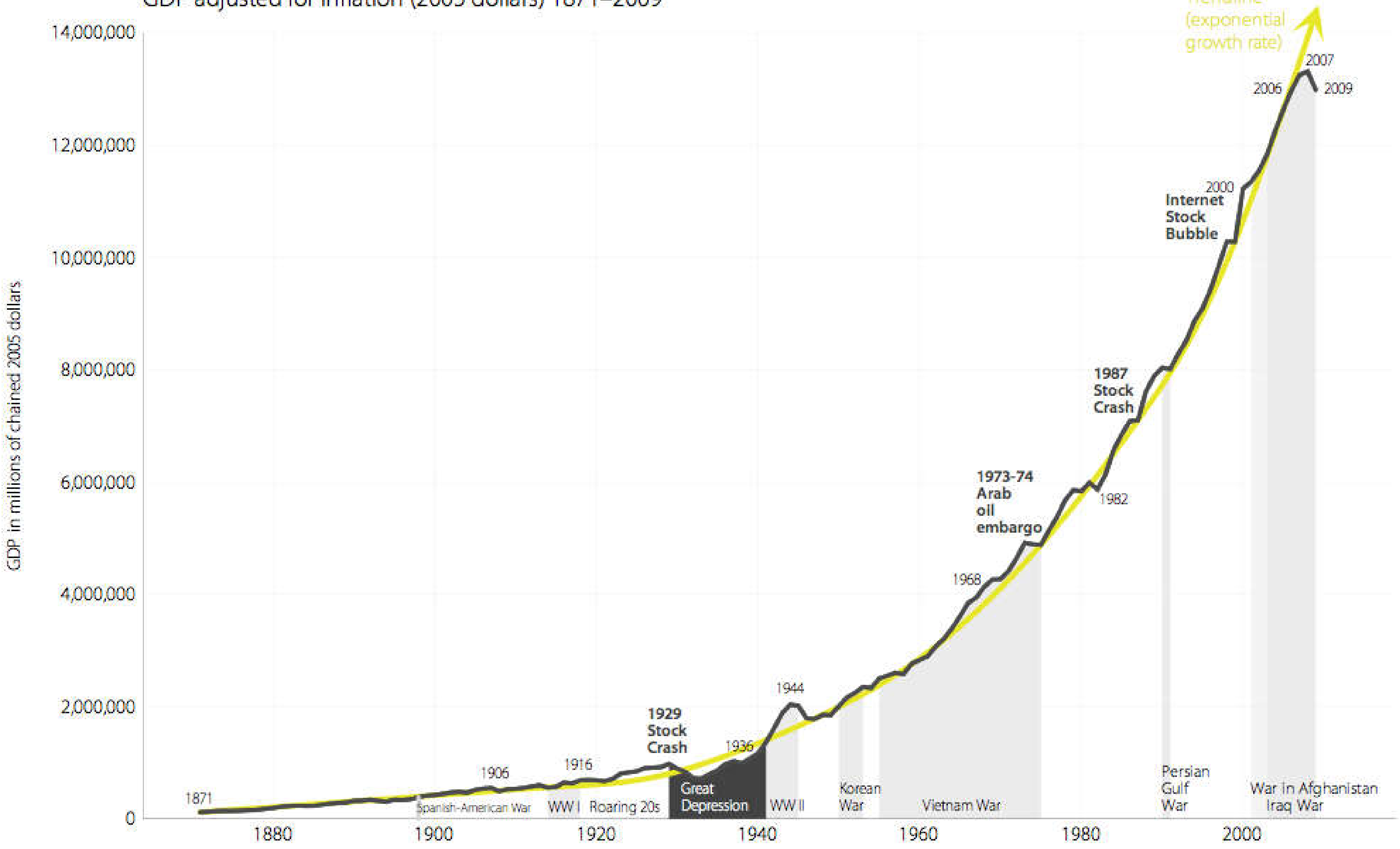
- Role of steam power
  - Newcomen engine (1712) – pumping water out of mines
  - Watt engine (1765) – separate condenser, increased efficiency, 25 year patent
  - Rotary engine (1789) – application to cotton mills
  - Steam-powered locomotive (1829) – for Liverpool-Manchester railway
- ‘Railway mania’ (1830s, 1840s)
  - Speculative investment in new railway lines (10,000 miles of track by 1860)
- Second surge
  - Rapid economic growth in 1850s and 1860s, due to: synergies between use of stationary steam power in factories, motive steam power for railways and development of machine tools
  - Complementary institutional innovations, e.g. factory working systems, joint stock companies

4th surge (rise of consumerism)

- 4th Surge
    - Associated with oil, automobiles and mass production
    - Began with opening of Ford Model T plant in 1908
    - Deployment began after 1945 as war production in US reoriented to domestic mass production
    - Suburbanisation as 'direction' for deployment, enabled by government policies to promote road- and house-building
- Rise of consumerism
    - Plentiful supplies of oil at price of around $2/barrel (nominal)
    - Plentiful supplies of coal for electricity generation
    - Economies of scale in supply and creation of demand in housing, leisure and electrical devices in the home
    - Significant increase in standard of living for most households

Long-term real growth in US GDP

GDP adjusted for inflation (2005 dollars) 1871–2009



Data from MeasuringWorth.com

VisualizingEconomics.com

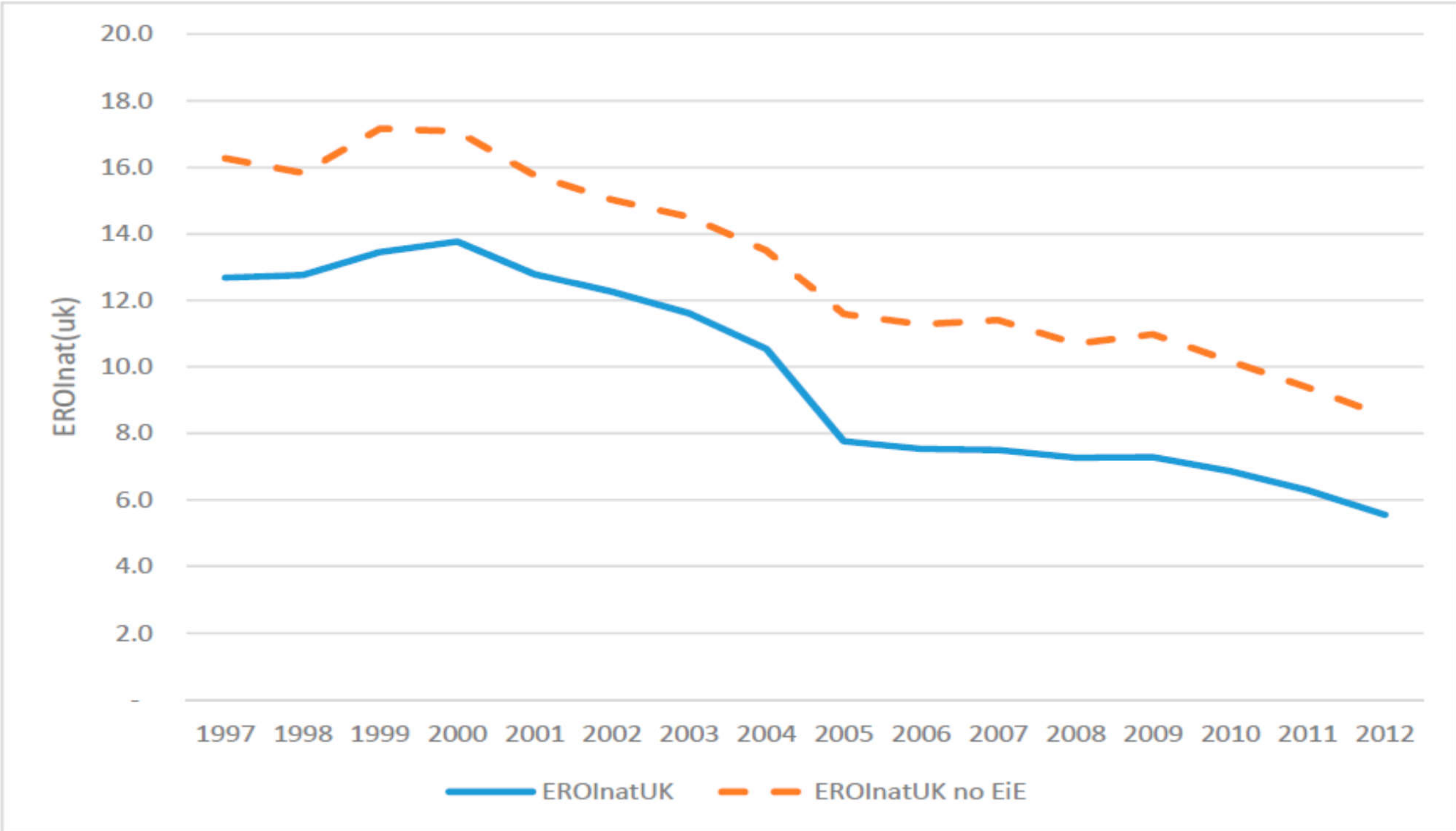
5th surge (deployment of ICT)

- Deployment of ICT-based surge after prolonged turning point:
  - 'dot-com' bubble in early 2000s, global financial crisis since 2008
  - Needs investment in productive capital and institutional changes to realise benefits of ICT roll-out
  - Role for government policies to provide 'direction' for roll-out
  - 'Green' can provide direction, including renewable energy technologies, circular economy, smart cities (Mazzucato and Perez, 2014)
- Challenges from techno-economic perspective
  - Dominance of neoliberal market thinking
  - Financialisation of economies
  - Weak legitimacy for government intervention

Declining net energy

- Net energy provided measured by EROI (energy return on energy invested)
  - Measures effects of technological innovation (that can improve net energy return) and resource depletion (that reduces net energy)
- Declining EROI for main energy sources
  - EROI for oil from around 80:1 in 1930s to around 20:1 now
  - Renewables also currently have low EROI values, but estimates vary and potential for EROI to increase with technological innovation
- Implications for economic growth
  - Charles Hall and colleagues argue that a minimum EROI of 5:1 is needed to maintain sustainable societies
  - They argue that high net energy enables discretionary spending in economy by households and businesses that drives economic growth

National EROI for UK (initial calculation)



Source: Brand-Correa et al. (2017), *Energies* 10, 534

New economic models

- Green growth
  - Investment in green technologies and infrastructure (linked to ICT) can deliver a new surge of economic growth and jobs
  - High level of economic growth in industrialised countries is necessary to generate investment under current economic and political system
- Post growth
  - Current growth model based on increasing energy inputs and environmental impacts
  - Level of decoupling envisaged in green growth scenarios is unfeasible
  - Climate change scenarios rely on unproven ‘net negative emissions’
  - Need to design economic systems to deliver wellbeing rather then growth, either through deliberate downscaling (‘degrowth’) or at least doing away with GDP as predominant indicator (‘agrowth’)

Challenges for policy-relevant analysis

- No theoretical model fully accounts for the roles of exergy efficiency, techno-economic surges and EROI in economic growth
  - What can we learn from current (partial) models?
- Mainstream models of endogenous economic growth do not account for energy inputs, but emphasise roles of human capital, skills and knowledge development in economic growth
  - How can these endogenous growth models be related to energy-dependent models of economic growth?
- Energy-dependent models use energy-augmented production functions
  - Can production function models incorporate dynamic interactions and evolutionary changes?
- Climate change mitigation requires urgent action
  - Need to incorporate energy dependency of economy in low carbon scenarios and analysis of industrial benefits to UK