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Complex systems methods for informing energy decision-making in cities

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PANDA (Patterns, Nonlinear Dynamics and Applications) seminar

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Outline

- EPSRC Energy and Complexity project
- What do we mean by complexity?
- Insights from:
  - Complexity economics
  - Innovation systems
  - Social network analysis
  - Transition pathways
  - Co-evolutionary approaches
- Bridging complex systems and the real world

EPSRC Energy and Complexity project

- EPSRC call "to develop and apply the tools and techniques of complexity science to energy research challenges"
- Project "Future energy decision making for cities – Can complexity science rise to the challenge?"
  - Interdisciplinary project team, including Schools of Environment, Environment and Maths (Leeds) and Computer Science (Nottingham)
- Approach:
  - Case study and dynamic network modelling of uptake of energy efficiency measures by households (Leeds)
  - Agent-based modelling of decision-making at individual/household level (Nottingham)
  - Interaction with Leeds City Council on their approach to strategic energy decision-making
  - 2nd case study of strategic energy decision-making at city level

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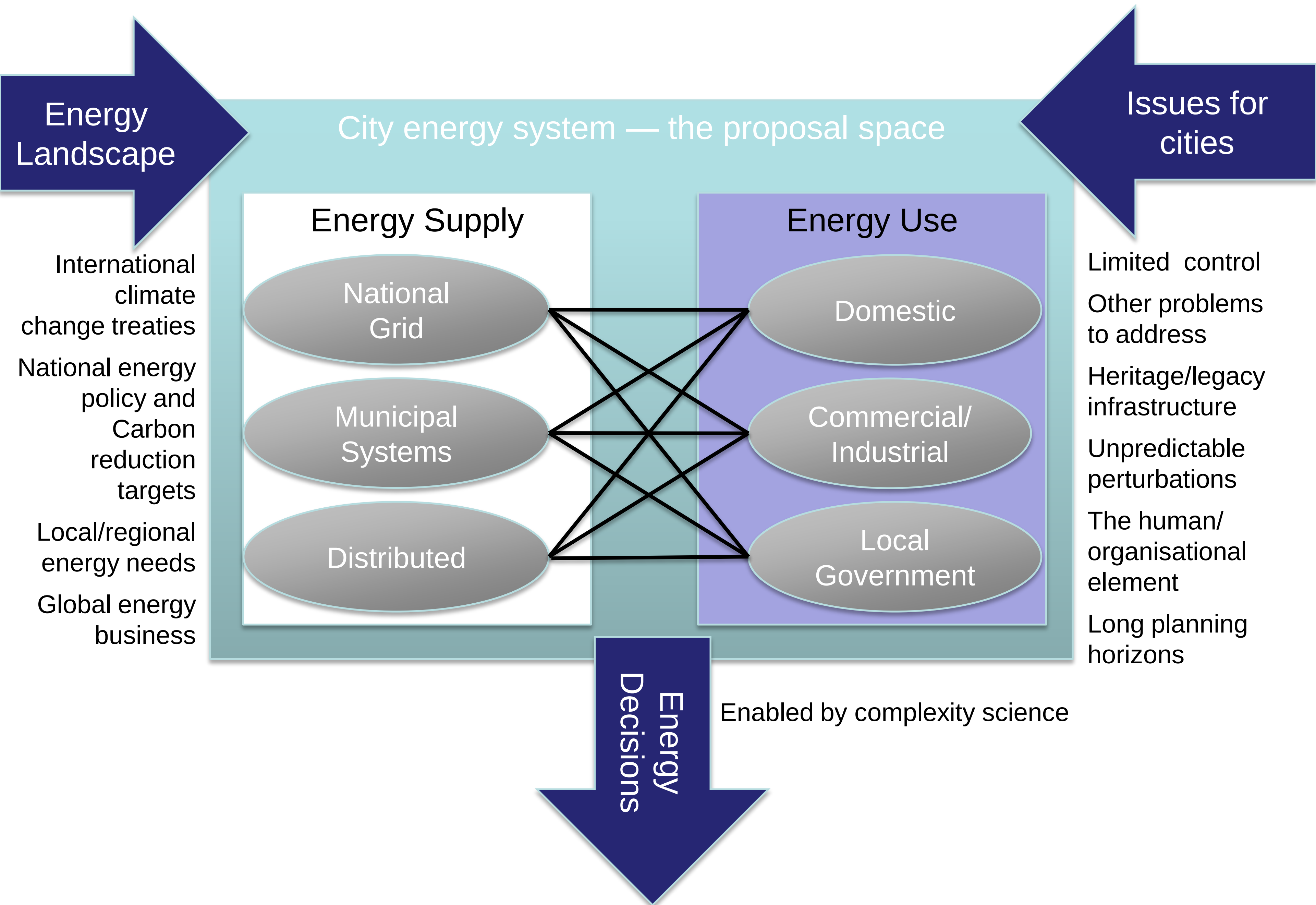

Energy Landscape
City energy system — the proposal space
Issues for cities
Energy Supply
Energy Use
National Grid
Municipal Systems
Distributed
Domestic
Commercial/ Industrial
Local Government
International climate change treaties
National energy policy and Carbon reduction targets
Local/regional energy needs
Global energy business
Limited control
Other problems to address
Heritage/legacy infrastructure
Unpredictable perturbations
The human/ organisational element
Long planning horizons
Energy Decisions
Enabled by complexity science

Complex adaptive systems (Beinhocker, 2005)

- *Dynamics*:
  - open, (non-linear) dynamic systems, far from equilibrium
- *Agents*:
  - made up of heteorogeneous agents, lacking perfect foresight, but able to learn and adapt over time
- *Networks*:
  - agents interact through various networks
- *Emergence*:
  - macro patterns emerge from micro behaviours and interactions
- *Evolution*:
  - evolutionary processes create novelty and growing order and complexity over time

Mapping between complex systems and energy systems

Complex systems ↔ Energy systems

Non-linear dynamics
Agents
Networks
Emergence
Evolution

Carbon reduction targets
Security of supply
Alleviating fuel poverty
Economic competitiveness

Qualitative and quantitative modelling

Qualitative and quantitative knowledge

Increasing returns to adoption of technologies (Arthur, 1989)

- Scale economies
  - spread fixed costs over increasing volume
- Learning effects
  - experience gained reduces unit costs
- Adaptive expectations
  - adoption reduces uncertainty, as users gain confidence in quality, performance, longevity
- Network or co-ordination effects
  - network benefits increase with more users

Technological lock-in

- Path dependence of development:
  - specific sequences of events
  - specific timing of outcome-shaping events
  - similar starting conditions leading to a wide range of possible outcomes
  - small events that can have large consequences
- Lock-in
  - increasing returns to adoption (positive feedback) can lead to lock-in of incumbent technologies

Systems thinking (Meadows, 2008)

- System is a set of interconnected elements coherently organised in a way that achieves something
  - May exhibit adaptive, dynamic, goal-seeking, self-preserving, and sometimes evolutionary behaviour
- System properties
  - Feedback loops (virtuous and vicious cycles), resilience, self-organisation, hierarchy (stable intermediate forms)
- System traps and opportunities
  - Tragedy of the commons
  - Drift to low performance
  - Escalation into arms race
  - Success to the successful (the Matthew effect)
  - Seeking the wrong goal

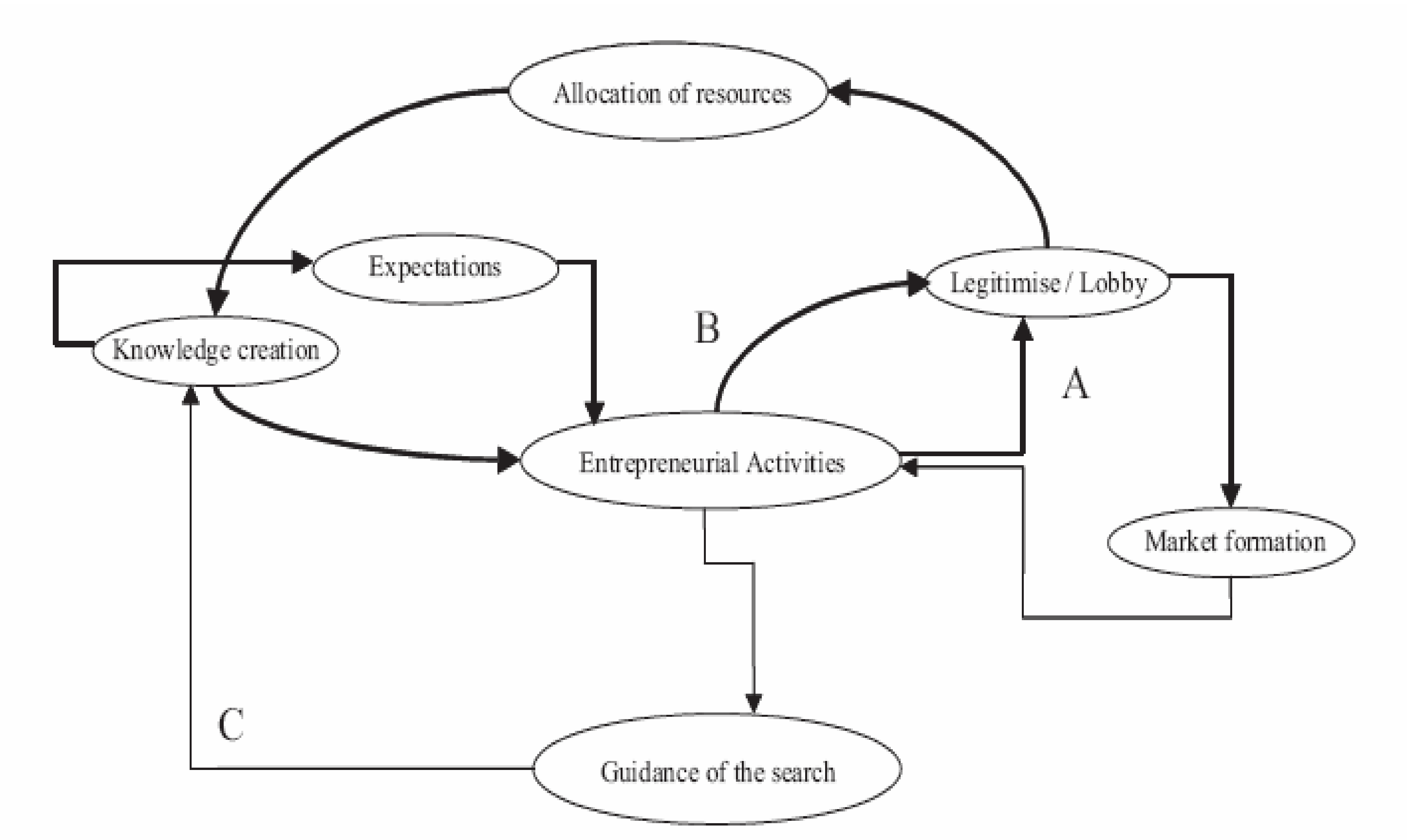
Innovation systems

- Innovation as a systemic, dynamic, non-linear process
    - Elements and relationships which *interact* in the production, diffusion and use of new, and economically useful, knowledge
    - Involving both market transactions and knowledge flows between users, producers & technology developers
    - Actors (and their competencies), networks and institutions
- Acting under uncertainty and ‘bounded rationality’ (agency)
    - Learning-by-doing, learning-by-using and learning-by-interacting
    - Importance of knowledge and skills
    - Role of expectations
- Influenced by prevailing institutional set up (structure)
    - Market rules
    - Policy and regulatory incentives and barriers

Functions of innovation systems
(Jacobsson and Bergek, 2004)

- Creation and diffusion of new knowledge
- Guidance of direction of search (expectations)
- Supply and allocation of resources, such as capital and competencies
- Creation of positive externalities
- Formation of markets
- Entrepreneurial activities
- Legitimising/lobbying

Virtuous cycles between key process in technological innovation systems



Source: Hekkert et al., 2007

Social network analysis

- ‘Strength of weak ties’ (Granovetter, 1973)
  - Strong ties: frequent and intense interactions, trust and reciprocity
  - Weak ties: more limited, but potentially useful interactions
  - Weak ties serve as bridges between otherwise disconnected social groups, and so help to spread information and influence
- ‘Bowling alone’ (Puttnam, 1995)
  - Bonding social capital: between members of same social group
  - Bridging social capital: between different social groups
  - Decline in bonding social capital, as people show more individualistic behaviours, e.g. bowling alone, rather than taking part in leagues
- Embeddedness (Granovetter, 1985)
  - Undersocialised representations, consisting of atomised individuals
  - Oversocialised representations, systems of norms and values, internalised through socialisation
  - Role of personal relations and social structures or networks

Network dynamics

- Networks:
  - Nodes represent actors, with properties associated with variables
  - Links represent connections, transmitting information or influence
  - Dynamics of variables governed by rules based on own and neighbours' states
- Dynamic features
  - 'Small worlds': a few distant connections can greatly enhance diffusion of information
  - Preferential attachment leads to scale-free distribution
  - Weakly connected communities are intermediate forms
- Further research needed:
  - Dynamics on networks vs dynamics of networks
  - Overlapping communities

Multi-level transitions approach

(1) Analysing historical dynamics of transitions using multi-level perspective (Geels, 2002)

- Landscape: broader cultural values and institutions
- Socio-technical regime: prevailing set of practices, technologies, skills, institutions, infrastructures
- Niches: Spaces partially isolated from regime where technological and social learning can occur

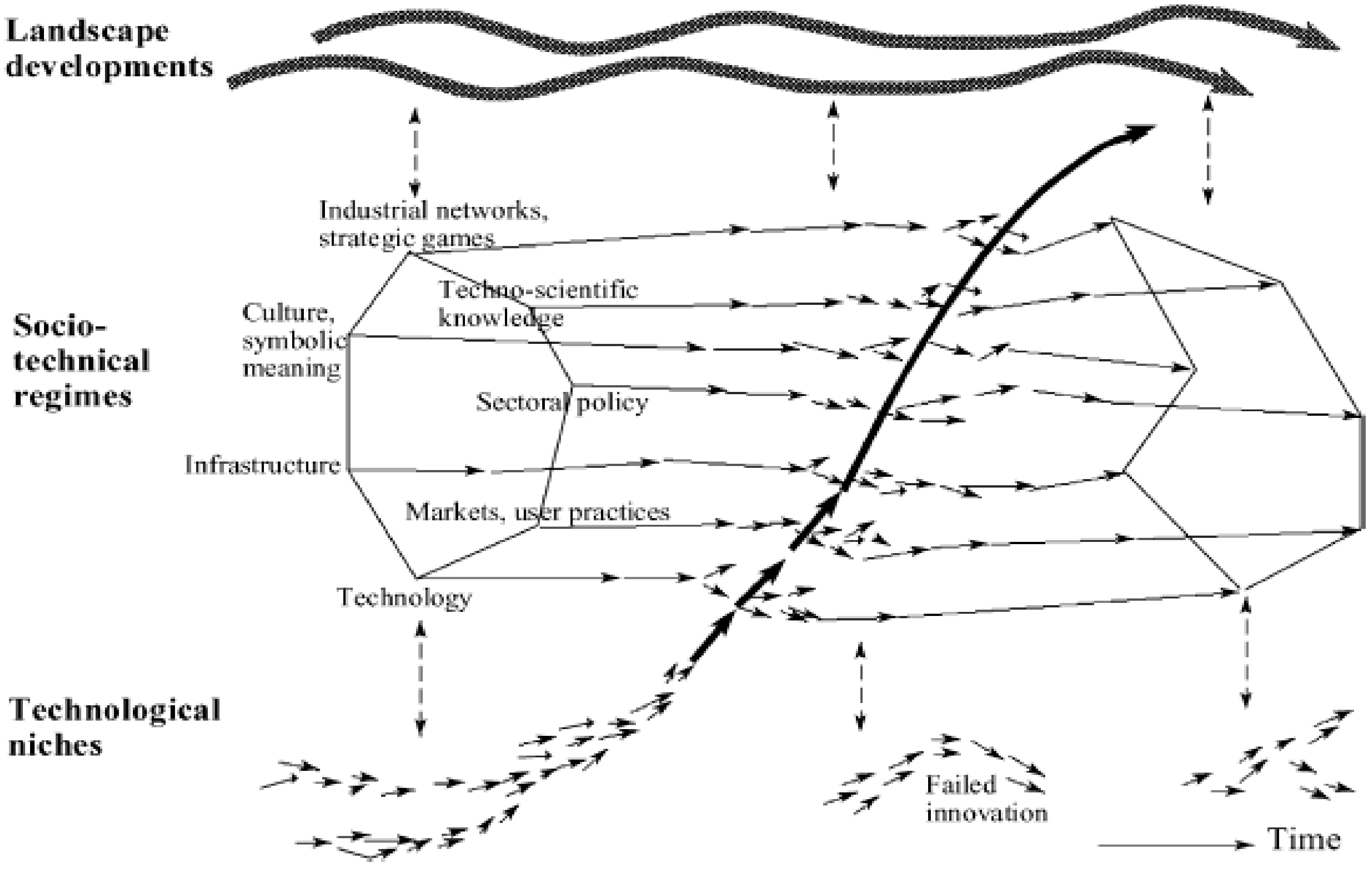
(2) Transition management as process of governance (Kemp and Rotmans, 2005, Loorbach, 2007)

- Modulate dynamics of transitions through interactive, iterative processes between networks of stakeholders
- Shared visions and goals; transition experiments
- ‘Transition arena’: innovation-oriented stakeholders

(3) Socio-technical scenarios

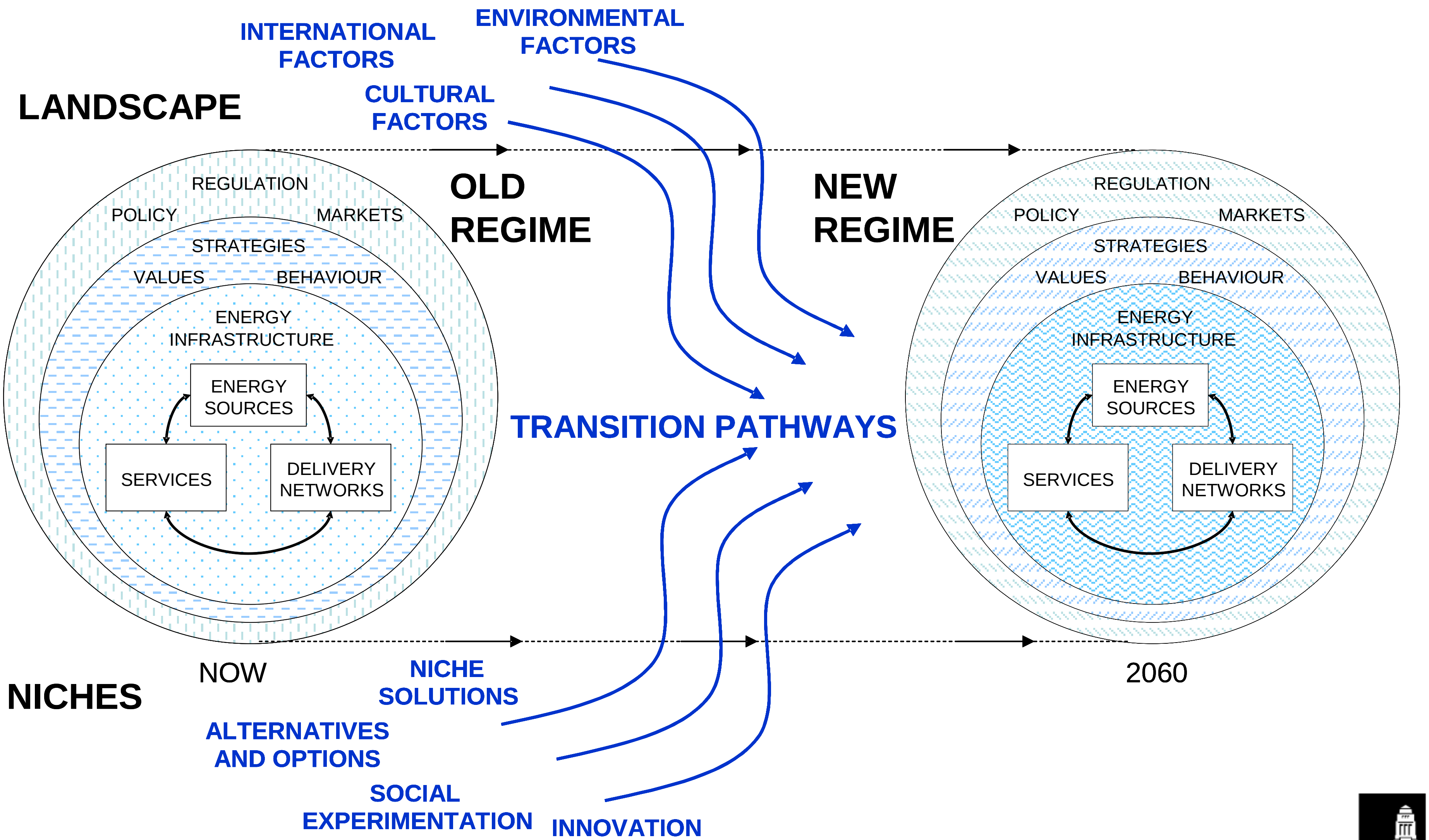
- Scenarios based on multi-level transition dynamics

Dynamic multi-level perspective on technological transitions



Source: Geels (2002)

Multi-level perspective for transition pathways



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Transition pathways to a UK low carbon electricity system

1) *Market Rules*:
   - Energy companies focus on large-scale technologies: nuclear power, offshore wind and capture-ready coal
   - Minimal interference in market arrangements
2) *Central Co-ordination*:
   - Greater direct government involvement in governance of energy systems, e.g. issuing tenders for tranches of low-carbon generation
   - Focus on centralized generation technologies
3) *Thousand Flowers*:
   - More local, bottom-up diversity of solutions
   - Local leadership in decentralized options

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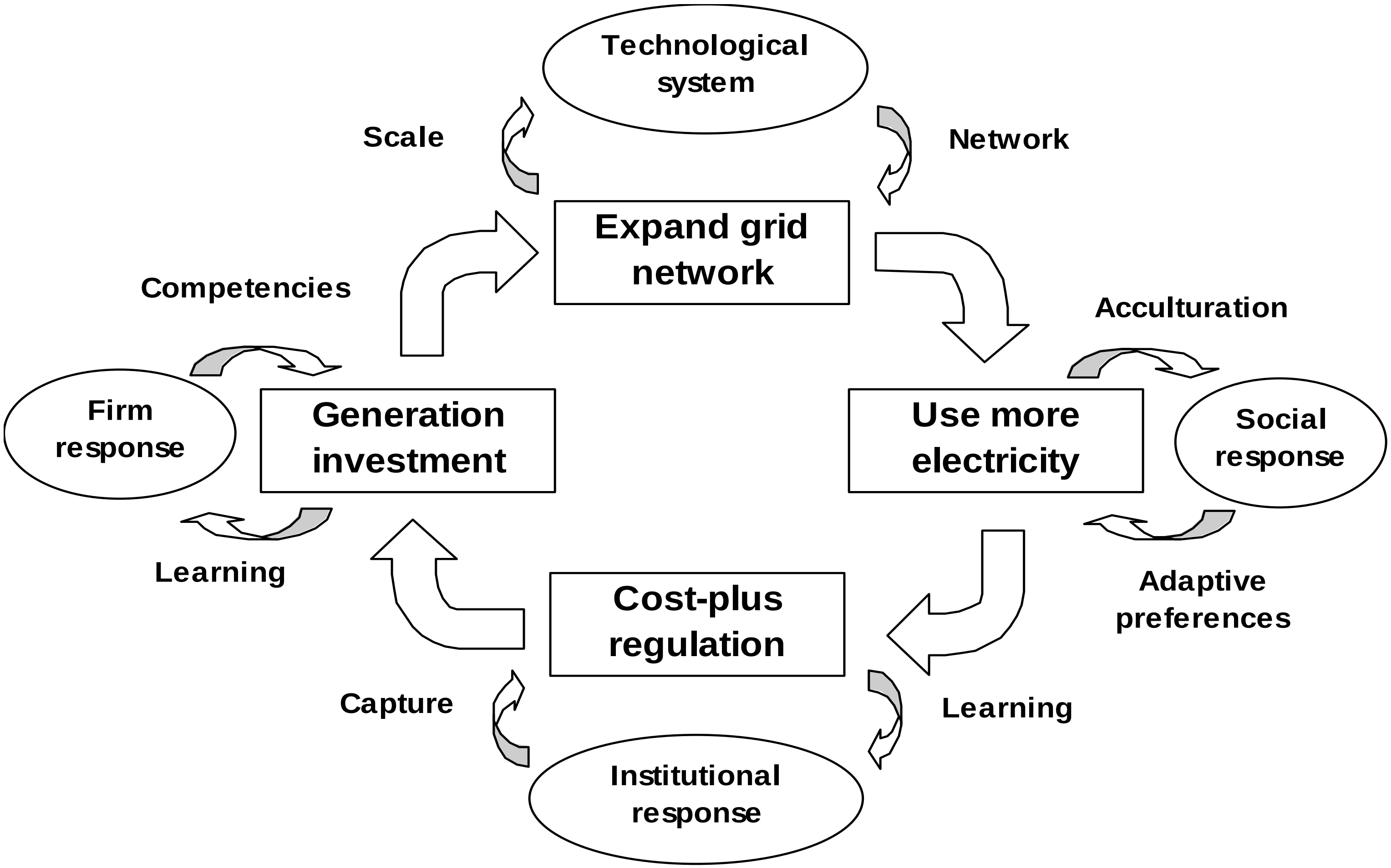
Co-evolution of technological and institutional systems

- Lock-in of technological and institutional systems
  - Interacting increasing returns to adoption of technologies and institutions
  - Techno-institutional system or complex becomes locked-in
  - Example of current carbon-based energy system (Unruh)

Electricity generation techno-institutional system



Source: Unruh (2000)

Co-evolutionary approaches

- Co-evolution of technologies, institutions and business strategies
  - Innovation systems and economic growth (Nelson, 1994, 2005)
  - Competition between industrial systems (Murmann, 2002)
  - ‘Origin of wealth’ in industrialised countries (Beinhocker, 2005)
- Co-evolution of ecosystems, technologies, institutions, business strategies and user practices (Foxon, submitted)
  - Causal influences between interacting systems, by altering *selection criteria*, e.g. a new incentive in the institutional structures increases the likelihood of a particular technology being adopted, or by changing the *replicative capacity* of individual entities, e.g. a firm adopts a new business strategy causing it to increase its investment in technological innovation.
  - Emphasises lock-in of current systems
  - But potential for rapid transitions if sufficient virtuous cycles can be created

Bridging complex systems and the real world

- Many modelling approaches
  - Network dynamics
  - Agent-based modelling
  - Diffusion/percolation models
  - System dynamics
  - Evolutionary models
- Each captures some complex systems or network properties
- Range of qualitative and (some) quantitative insights about features of the real world, from complexity economics, innovation systems, transition pathways and co-evolutionary approaches
- Modelling can usefully build on, test and develop these insights

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