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International Symposium 2026

A Meta-Methodological Systems Exploration to Inform the Energy Transition

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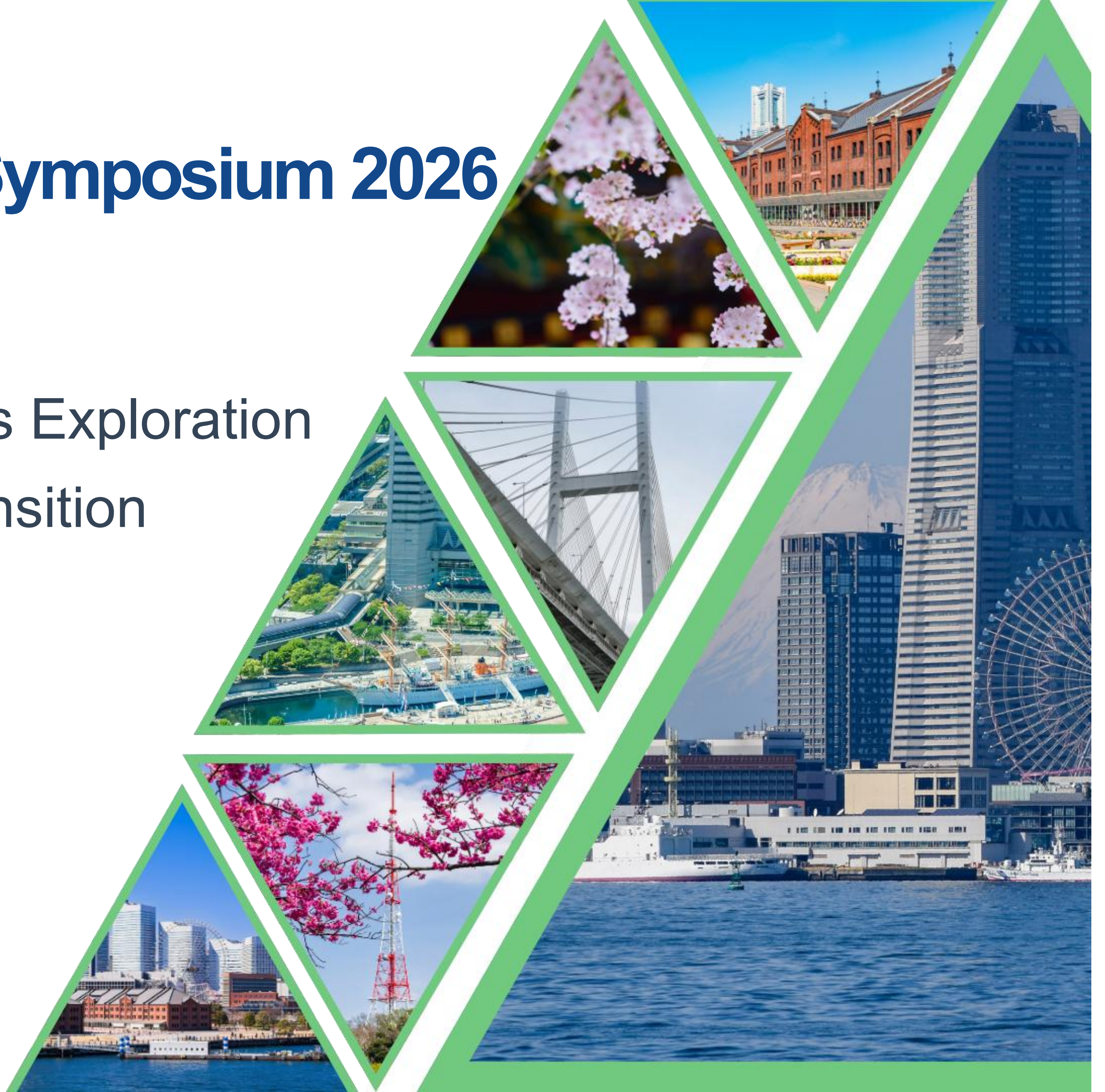

Outline

- Overview of the Global and Australian energy decarbonisation context
- Systems approaches
- Critical Systems Thinking & Practice (CST/CP)
- What can CST/CSP tell us about electricity system decarbonisation
    1. Identification of the System of Interest
    2. The five systemic perspectives
    3. The system boundary
    4. Identification of primary and secondary issues
    5. An NEM Value Model
    6. Classification of the SoI and a proposed SE approach
- Conclusion

Presentation Purpose

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- The Australian electricity system is transitioning from carbon-intensive energy sources to renewable energy

- This case study aim to:

  1. Identify the issues that need to be addressed in the transition to a fully decarbonised electricity system that delivers
     - required electricity services while satisfying stakeholder needs, and
     - satisfies constraints relating to security of supply, affordability, reliability, resilience, environmental sustainability, economic viability, regulatory compliance, and social acceptability

  2. Evaluate the utility of the Tradecraft Guide to select systems engineering approaches for this transition

The Provision of Energy is a Global Systems Challenge
INCOSE Vision 2035 (INCOSE, 2021)

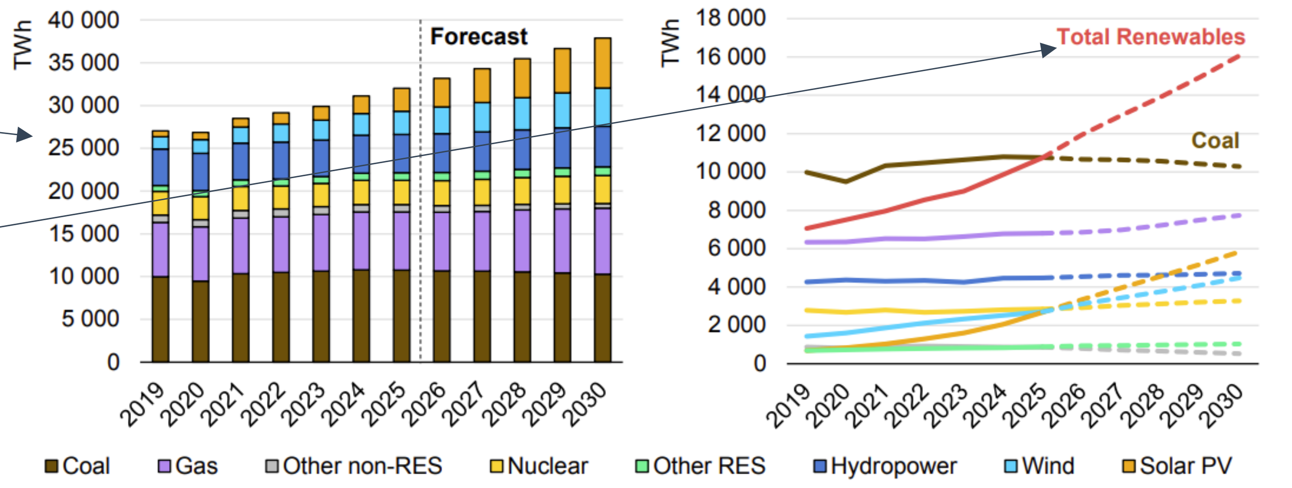
- Major societal challenges such as climate change, pandemic response, and global access to healthcare are, at their core, global systems challenges.
- Solutions to address these challenges require overarching systems analyses and perspectives.
- Systems engineers will, by 2035, bring an increasingly wider systems thinking perspective and perform modeling, simulation, and tradeoff analysis.
- Systems engineers can help analyze the interactions across natural and human systems to inform and shape the development of mitigation approaches that address the tradeoffs in feasibility, cost and benefits.

Global Context of Decarbonisation (IEA, 2022, 2205, 2026)

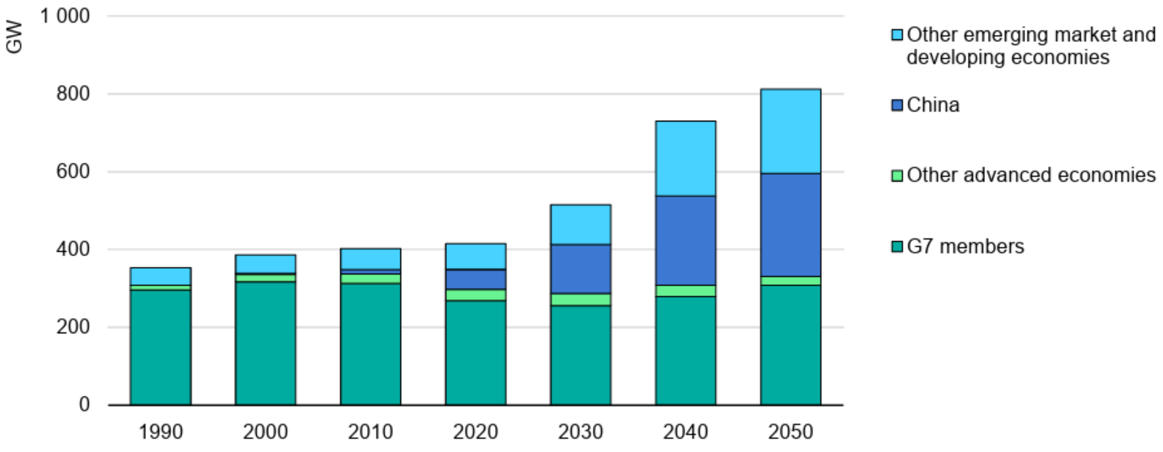
- Energy demand is rising – an indicator of improving living standards
- Global energy mix changing in response to climate change
- Primary energy generation growth is in renewable energy: solar PV and wind
- Nuclear energy also growing
- Fall in coal as an energy source in advanced economies

Global electricity generation by source, 2019-2030

IEA, (2026)

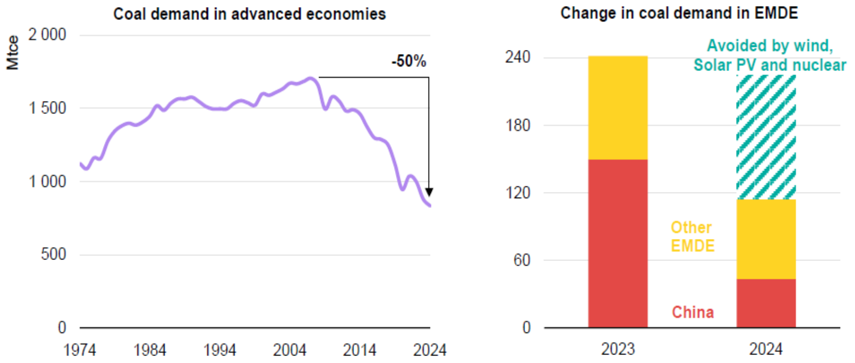


Nuclear power capacity by country/region in the Net Zero Emissions by 2050 Scenario



IEA, (2022)

Coal demand in advanced economies, 1974-2024, and change in coal demand in emerging market and developing economies in 2023 and 2024



IEA, (2025)

Scope of Complex Energy Decarbonisation Systems

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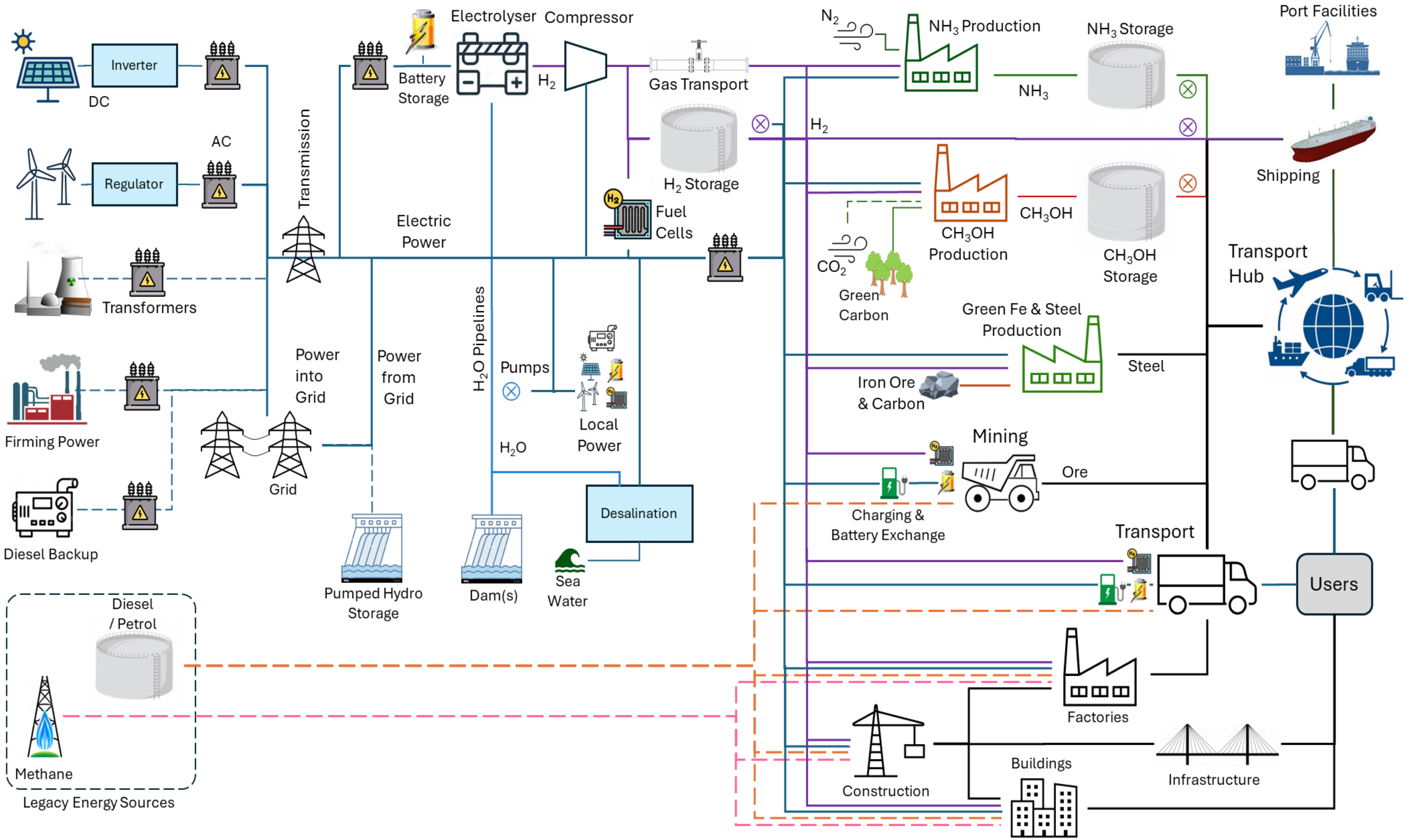
- **Energy Generation:** Solar, Wind, Nuclear, Energy Firming + Legacy systems
- **Transport:** Haulage, Rail, Air, Maritime, Hubs
- **Mining & Agriculture**
- **Industrial Production**
  - Materials – H2, NH3, Methanol, Toluene …
  - Heavy industries: Green Fe & Steel, Cement
  - Decarbonised factory production
- **Buildings and Construction**
- **Defence**



The Australian Govt Response: Australia's Net Zero Plan (DCCEEW, 2025)

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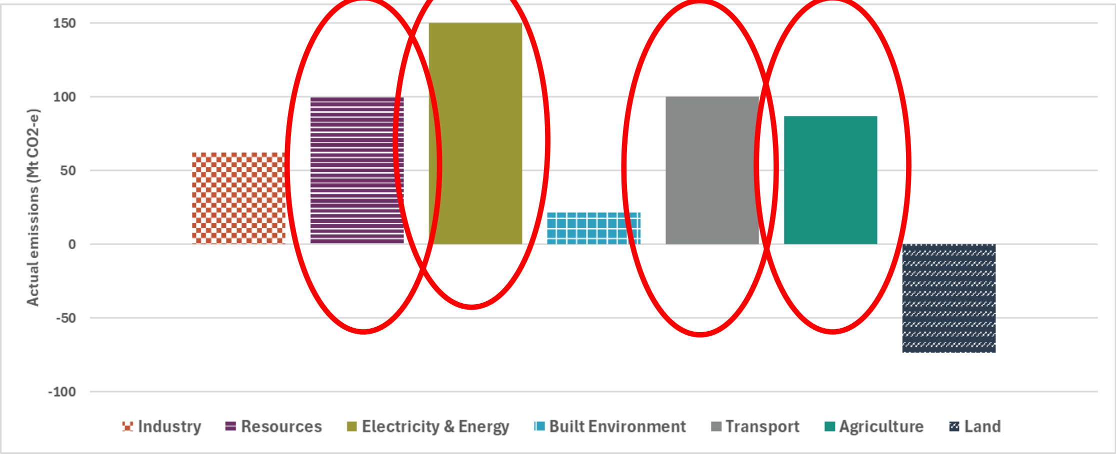
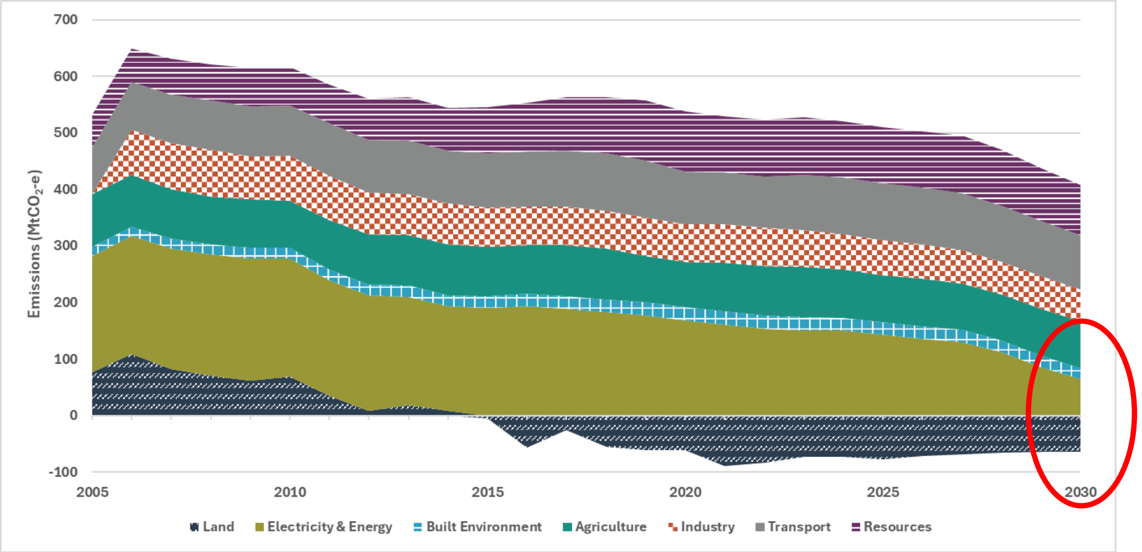
- Focusses on five areas:
  - Clean electricity across the economy
  - Lowering emissions by electrification and efficiency
  - Expanding clean fuel use
  - Accelerating new technologies
  - Net carbon removals scaled up
- Electricity and Energy contributes 34% of CO_2
  - Electricity, manufacture of petroleum products & supply of gas
- Emission projections show that the "Electricity and Energy" category is to provide the greatest reductions over the next few years
- Electrification of transport, resources and agriculture is set to reduce CO_2 much further hence:

The key to achieving net-zero is through decarbonising electricity



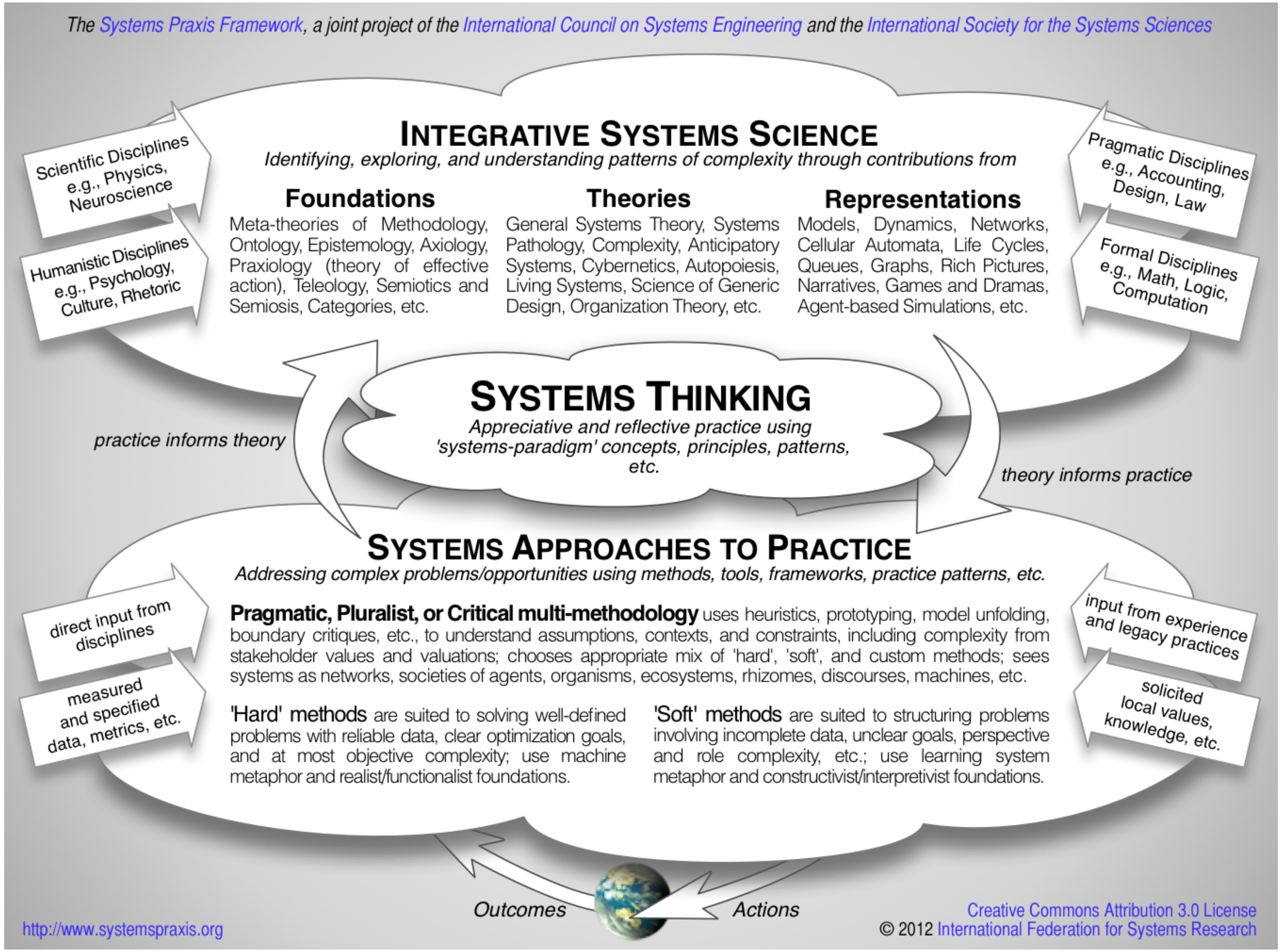
Australia's emissions by sector 2024 (p31)



Australia's emissions projections (p33)

Systems Approaches Arose to Deal with Complexity

- Practitioners need to take a broad approach that acknowledges, understands, and works with complexity.
- Systems thinking underpins all systems practices.
- A multi-methodological toolbox is needed to address broader energy challenges



From Systems Thinking to Complex Systems Practice
(Jackson, 2024 attributed to Johnson, 1980)

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- Metaphors help us map problem situations to approaches
- The puzzle metaphor

  "Traditional approach where problems are thought of as ***puzzles*** *– and once solved, they are solved forever."*

  Well-suited to traditional projects

- The chemical metaphor
  - *"To live by the* ***chemical metaphor*** *would be to accept it as fact that no problem disappears forever. Rather than direct your energies towards solving your problem once and for all, you would direct your energies towards finding out what catalysts will dissolve your most pressing problems for the longest time* without *precipitating worse ones."*
  - Reappearance of a problem is viewed as a natural occurrence rather than a failure on your part to find "the right way to solve it".

  Well-suited to complex, socio-technical problems spaces

    - e.g. Infrastructure, health care, supply chains, industrial relations, energy systems, etc

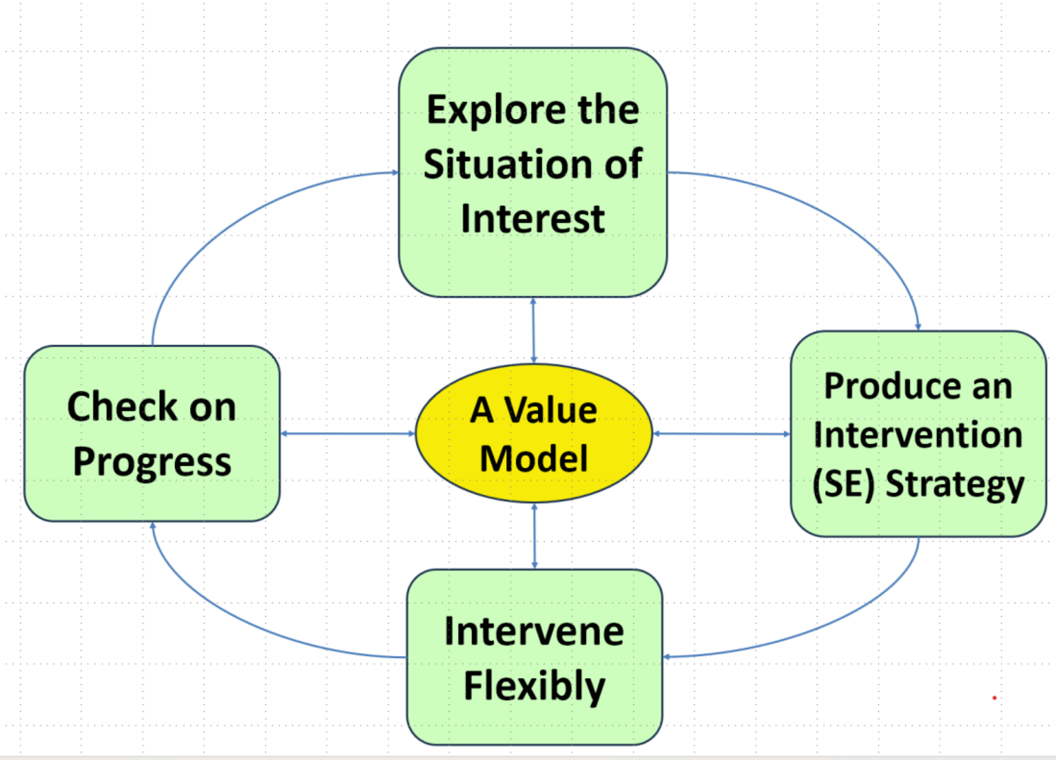
  - The Tradecraft Guide is mostly focussed on this class of problems

A Systems Framework for Addressing the Energy System

- The energy system is best addressed through the chemical metaphor
- Need to recognise that energy systems are truly complex and have wide-ranging impact:
  - Economic
  - Social
  - Environmental
- Energy systems interact strongly with the external environment so will need to be continually evolved
- Hence, need to understand the embrace the richness of the problem space
- Jackson champions Critical Systems Thinking (CST) for choosing and applying systems approaches to such problems
- CST aims to determine the right course of action for a situation of interest and seeks answers to penetrating questions

The Multi-methodological Critical Systems Practice Approach (Jackson, 2024)

- All systems approaches need to be tailored to suit the situation of interest (SoI); even more important for complex systems
- Jackson's ***EPIC*** formulation, (with concepts added from Hitchins and Hall) helps design the overall approach and guide its execution
- It is cyclic - most complex systems will require ongoing interventions and upgrades
- Just like Agile approaches, it eschews detailed pre-specification and can be adjusted and replanned every few weeks as needed
- Many interventions – both in technical projects and organisational changes occur simultaneously and asynchronously
- The stages can operate concurrently
- EPIC model augmented by the addition of a value model drives decision making



A Process for Critical Systems Practice (EPIC+)

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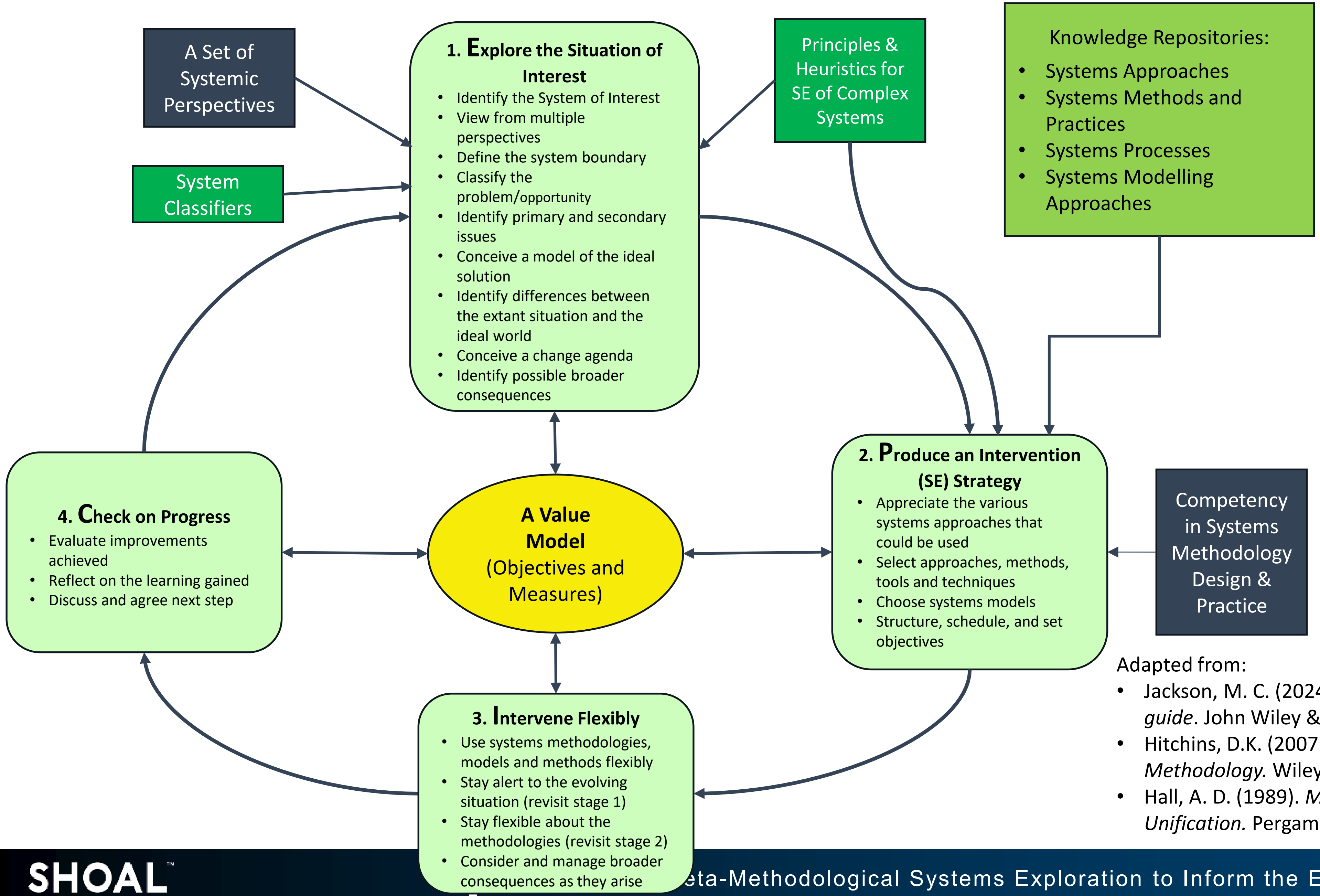

Adapted from:

- Jackson, M. C. (2024). *Critical systems thinking: A practitioner's guide*. John Wiley & Sons.
- Hitchins, D.K. (2007). *Systems Engineering: A 21st Century Methodology.* Wiley.
- Hall, A. D. (1989). *Metasystems Methodology: A new Synthesis and Unification.* Pergamon Press.

Let’s Step through the Process Steps for “Explore”

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1. Identify the System of Interest
2. View from multiple perspectives
3. Define the system boundary
4. Identify primary and secondary issues
5. Conceive a model of the ideal solution – a Value Model
6. Classify the problem/opportunity and identify suitable approaches
7. Identify differences between the extant situation and the ideal world
8. Conceive a change agenda
9. Identify possible broader consequences

1. Identifying the System of Interest

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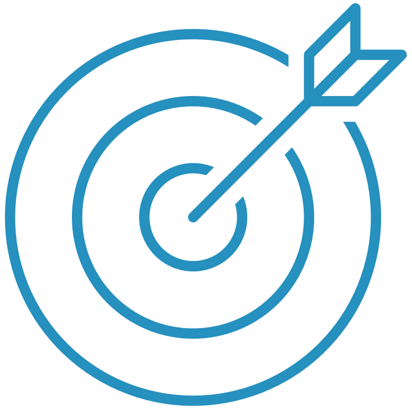
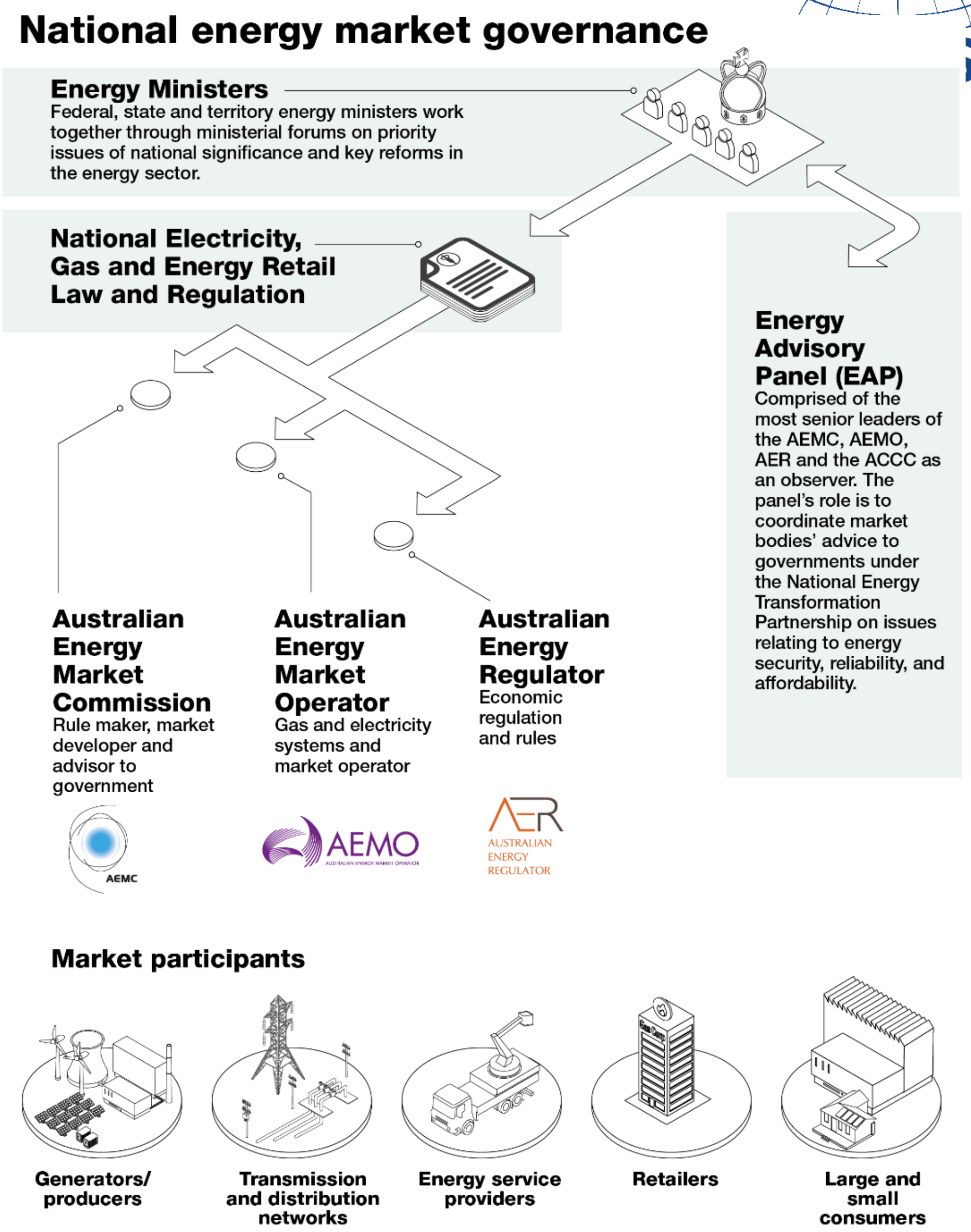
- Initially, the focus was on electricity generation
  - “Renewables are the cheapest form of energy.”
  - Misses the vital point that the grid must be rebuilt to use Variable Renewable Energy
- Better to focus on the grid
  - However: ignores the human behaviour introduced by using an energy market construct
- Need to look at the electricity generation and distribution system at the level of the National Electricity Market



The National Electricity Market
(AEMO Fact Sheet, 2026)

- Australia's NEM commenced in 1998
- End-to-end distance of more than 5,000 kms with 40,000 kms of high voltage transmission lines.
- ~200TWh of electricity traded (FY 25) worth > $25bn
- Serves 23 m people; 85% of Australia's population
- Many players
  - Multiple jurisdictions
  - ~ 650 participants: generators, network owners, retailers, large energy users
  - > 300 generators
- Provides a mechanism for privately funded components to provide infrastructure & services on a commercial basis
- Central operational management strengthening over time
- Central planning but new generation and services dependant on market response or State or Australian Government intervention.
- NEM comprises governance + rules + institutions + participants



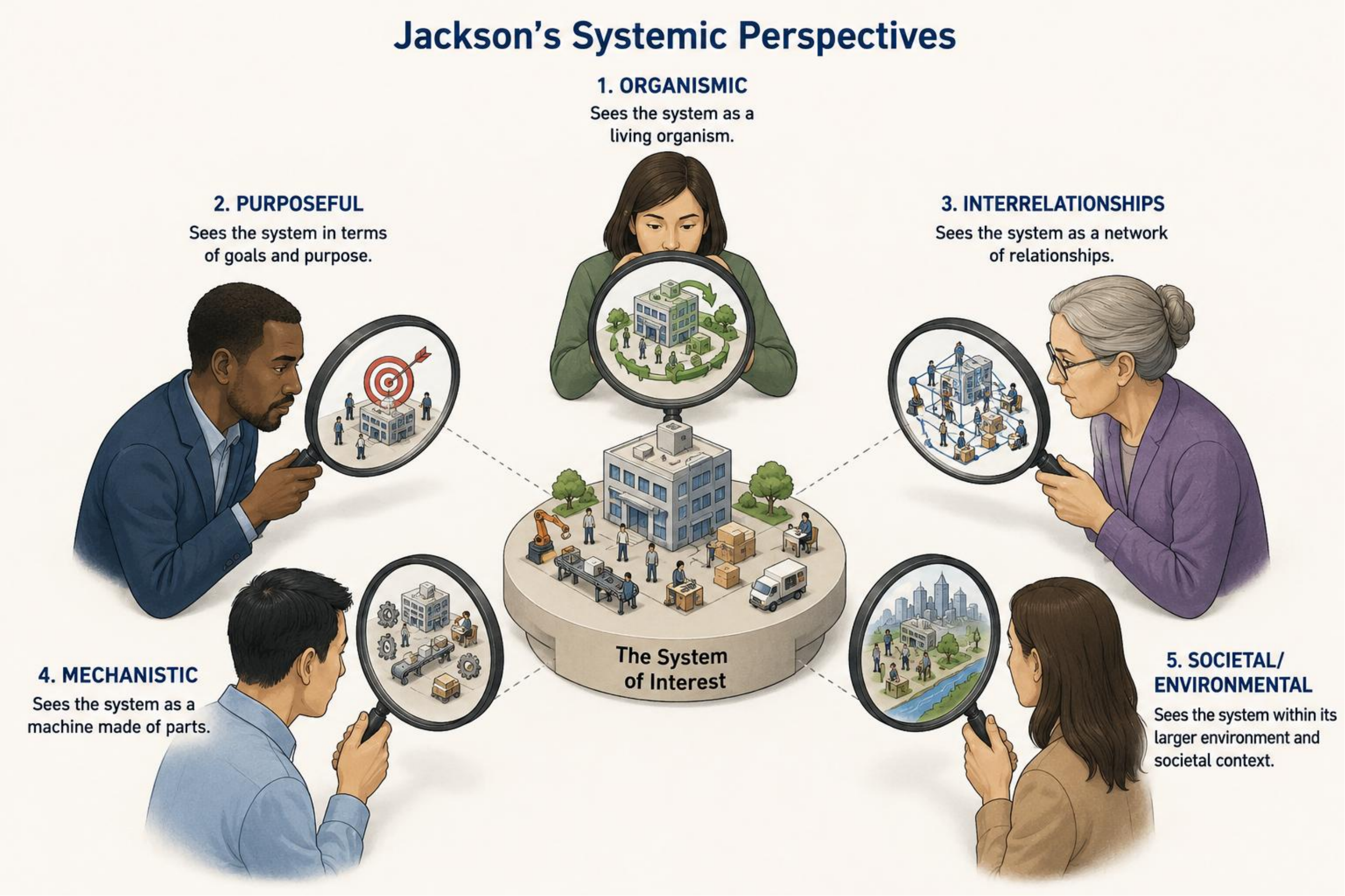
2. Viewing the SoI from Systemic Perspectives

(Jackson, 2024)

Each perspective teases out a *world hypothesis*; a paradigm

CST Systemic Perspectives are considered necessary and sufficient.

Perspective	Summary
Mechanical	The engineering mindset applied to systems: clear goals, efficient input-output processes, and hierarchical control.
Interrelation-ships	Understanding the complex web of cause-and-effect relationships within systems, considering feedback loops, delays, and interconnected variables.
Organismic	View the system as a living organism that must adapt to survive.
Purposeful	People have their own mental models; reality is socially constructed through negotiation between different viewpoints.
Societal/ Environmental	Consider who benefits and gets hurt by the system, including future generations and the environment.



Insights from the Mechanistic Perspective (1)

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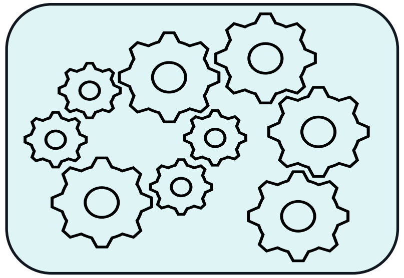
- NEM technical characteristics:
  - Need an exact balance between continually varying electricity supply and demand
  - System boundary not obvious
    - NEM comprises governance + rules + institutions + participants + infrastructure
  - Many participants, large and very complex – large number of control loops.
  - Many legacy components poorly suited to a grid with variable renewable energy
  - Must meet demanding technical requirements – see later.
- NEM market characteristics
  - It's a market for trading energy – like the stock market wholesale process vary continuously and are often negative
  - Energy market not a capacity market – special mechanisms needed to ensure system strength, frequency and voltage control as well as adequate peak capacity
  - Dynamically managed by AEMO



The engineering mindset applied to systems: clear goals, efficient input-output processes, and hierarchical control.

Insights from the Mechanistic Perspective (2)

- Development impacted by uncertainty
  - Demand uncertainties
    - Timing of electrification of transport, industry, mining, agriculture …
    - Uptake rate of Consumer Energy Resources
  - Technology is rapidly advancing
    - Energy storage, energy generation, energy transport
    - Challenging for investors seeking to achieve a return on investment on infrastructure
  - Most energy projects are running late – undermining grid-development timelines

The engineering mindset applied to systems: clear goals, efficient input-output processes, and hierarchical control.

  - Grid increasingly needs more transmission lines, additional system services, and distribution redesign to cope with:
    - Base-load generation decommissioning
    - Increasing Variable Renewable Energy penetration
    - Proliferation of Consumer Energy Resources
  - However, the need is often discovered after analysis of major blackouts.

Insights from the Mechanistic Perspective (3)

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- Feasibility considerations of Net Zero by 2050 seemingly overlooked:
  - Estimated cost > 1 trillion $AUD to achieve net-zero electricity grid by 2050 in Australia
    - The private sector is assumed to provide much of this (AEMO, 2024)
  - The materials and manpower to construct the necessary transmission lines (10,000km) and other infrastructure may not be feasible in the timescale (Briggs, 2026)
  - Gross underestimation of energy storage required (Payne et al., 2026)
  - Many key technologies yet to mature, eg grid-level energy storage
  - Planned penetration of rooftop solar (AEMO, 2024) will require the rewiring of local distribution grids to maintain minimum requirements: voltage drop/rise, phase angle
  - Multi-day wind droughts have proven worse than expected over the last few years

The engineering mindset applied to systems: clear goals, efficient input-output processes, and hierarchical control.

Insights from the Interrelationships Perspective

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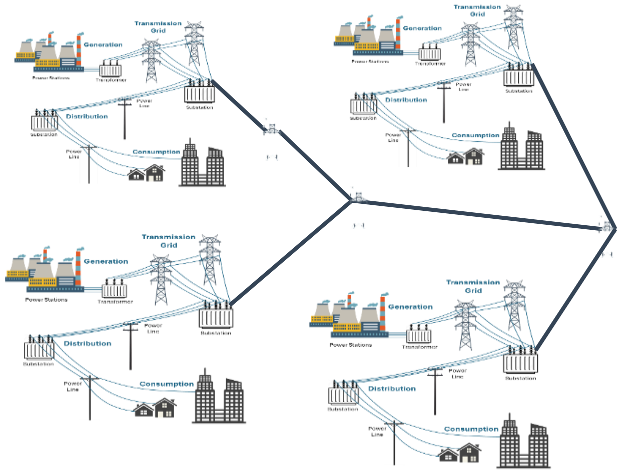
Understanding the complex web of cause-and-effect relationships within systems, considering feedback loops, delays, and interconnected variables.

- The NEM is best viewed as a System of Systems with participants seeking their own goals
- NEM governance and regulation is complex with many participants that can impact system behaviour
- At the grid level, all the components are connected in the form of a grid of grids with finite interconnection capacity
- There are control loops at every level that influence:
  - Long-term planning in response to anticipated electricity demand, weather patterns, etc.
  - Refinement of market rules in response to NEM behaviour
  - Provision of operational reserves to meet expected demand and contingency
  - Provision of electricity supply on a 5 min basis to meet actual needs
  - Increasing transmission capacity to enable the integration of renewable energy
  - Dynamic control of generation for electricity supply in various timescale down to 5 minutes
  - Electricity system operational control – generator management
  - Electricity system control of key characteristics voltage, frequency and their stability
  - Characteristics management – system strength and other contingency requirements
  - Planned event management – maintenance
  - Unplanned event management – in the millisecond region



- AEMO, the market operator, has been granted greater powers in recent years to deal with frequent market stresses – has successfully managed a large and increasing number of market issues in recent years

Insights from the Organismic Systems Perspectives

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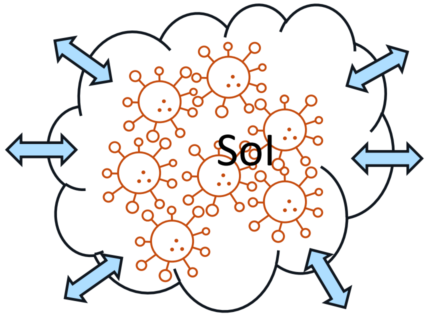
- A range of external relationships shape the development of the NEM
  - Government imperatives to move to renewables
  - Market intervention by Federal and State governments
  - Technology-driven changes in demand profiles: datacentres, BEVs
  - Community concern about electricity price rises and their impact on disadvantaged people
  - Community objections to renewable projects
  - Subsidies for Consumer Energy Resources
  - The willingness of private capital to invest in new infrastructure

Understanding the complex web of cause-and-effect relationships within systems, considering feedback loops, delays, and interconnected variables.

- A range of external relationships also cause the operation of the NEM to adapt
  - Short-medium term: weather, diurnal patterns, load patterns
  - Longer-term: climate change, changing consumer demands (transport electrification), changing investment environment & subsidies

- Not a one-way interaction, the NEM changes its external environment through:
  - Pricing de-industrialising country
  - Capability perceptions influence investment decisions (e.g. data centres)
  - Absorbing capital



Insights from the Systemic Perspective (1)

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People have their own mental models; reality is socially constructed through negotiation between different viewpoints.

- Governance stakeholders are seeking to evolve and operate the NEM in a way that meets the Power System Requirements (AEMO, 2020)

Technical attribute and section of report where addressed	Requirement	Service(s) needed to meet requirement
Resource adequacy and capability • There is a sufficient overall portfolio of energy resources to continuously achieve the real-time balancing of supply and demand. (See Section 3.1)	Provision of sufficient supply to match demand from consumers	Bulk energy Strategic Reserves
	Capability to respond to large continuing changes in energy requirements	Operating reserves
	Network transport capability	Transmission and distribution services
Frequency management • Ability to set and maintain system frequency within acceptable limits. (See Section 3.2)	Frequency within limits	Inertial response Primary frequency response Secondary frequency control Tertiary frequency control
Voltage management • Ability to maintain voltages on the network within acceptable limits. (See Section 3.3)	Voltage within limits	Slow response voltage control Fast response voltage control System strength
System restoration • Ability to restart and restore the system in the unlikely event of a major supply disruption. (See Section 3.4)	Ability to restore the system	Black start services Restoration support services

Table from AEMO, (2020)

Insights from the Systemic Perspective (2)

People have their own mental models; reality is socially constructed through negotiation between different viewpoints.

- Non-government participants need to seek a return on investment.
- Large consumers want very reliable power, in large quantities, now and in the future at a competitive cost.
- Critical industries and services like hospitals value availability over cost.
- Low income households are very price sensitive and want solid availability.
- Wealthier domestic consumers welcome the opportunity to invest in Consumer Energy Resources any gain income from arbitrage.
- Certain elements of the community care most about net-zero.
- Business groups care about the current and future business environment and international competitiveness.
- etc

(When updating the Integrated Systems Plan AEMO engages with thousands of stakeholders to understand their appreciative systems.)

#5 The Societal/Environmental Systemic Perspective

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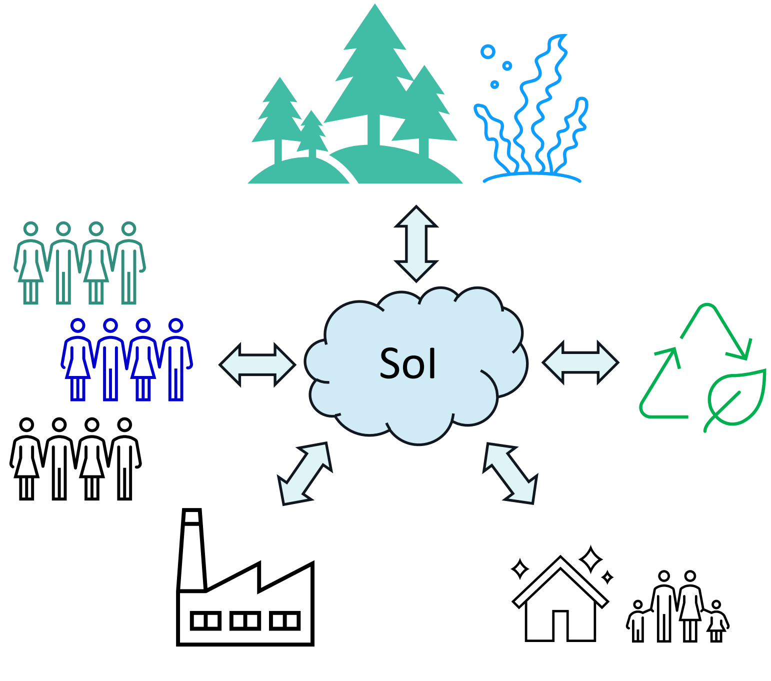
- Draws attention to the wide variety of stakeholders and the environment that might be impacted by the system
- Highlights that organisations must also consider suppliers, employees, customers, communities, future generations, wildlife, and the environment.
- It examines potential oppression of stakeholder groups and seeks to give voice to the disadvantaged
- It includes the desire to respond vigorously to local and global environmental issues

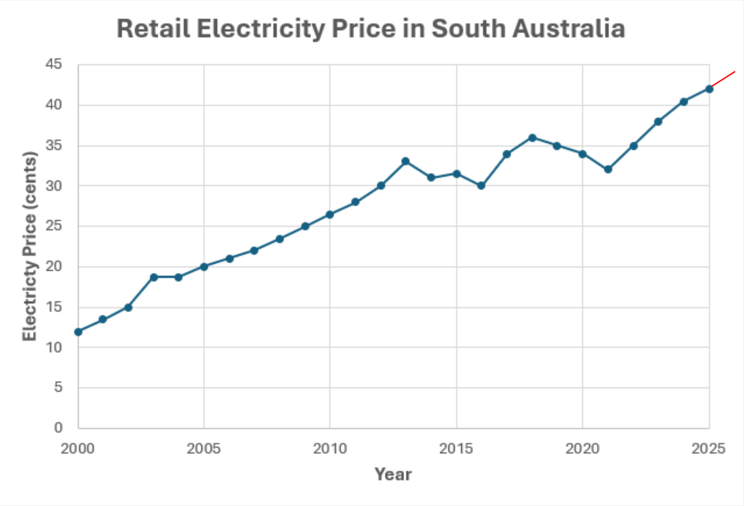


Multiple societal views and the impact of interactions with the environment
- Understand global impact & impact on disadvantaged

Insights from the Societal/Environmental Systemic Perspective (1)

- **Societal**
  - Low-income households, especially renters, are most affected by large power cost increases
    - The cost-of-living crisis features daily in the media
  - Businesses are impacted by higher costs;
    - Insolvencies rising
    - Energy-intensive industries declining
    - Investment and viability of data centres questioned
  - The boundary of the system changes depending on the stakeholder worldview:
    - Some focus on electricity system where the leading metric is renewable energy penetration
    - Others include the gas in the energy system
    - Others consider that the system extends to all the consumers not just large users and retailers

Consider who benefits and gets hurt by the system, including future generations and the environment.



Insights from the Societal/Environmental Systemic Perspective (2)

- **Environmental** concerns arising from decarbonisation efforts are now receiving public attention:
  - PV panels contain toxic materials and are banned from landfill in some jurisdictions. Recycling has commenced but is yet to be scaled up to reflect the predicted volume of PV panel waste
  - Wind turbine blade recycling is difficult although pilot plants are being built
  - Battery recycling is yet to mature to deal with the volume predicted
  - Electrolysers use large quantities of rare earths and rare noble metals but have a short life
  - The embedded energy of renewable energy systems and the energy needed to recycle them is glossed over
  - Renewable energy grids require significant additional transmission capacity to connect-up remote generation sites and provide geographical diversity – environmentally intrusive, expensive, material-intensive, and contain significant embedded energy.

Consider who benefits and gets hurt by the system, including future generations and the environment.

Wider Environmental Concerns of “Renewables”

- Native forests fragmented by 40-60m haulage roads for wind turbines; estimated 29,000ha to be cleared in QLD.
- Lithium mining by brine extraction is energy intensive and can lead to water pollution, land degradation and loss of biodiversity (Earth.org).
  - Also uses significant water - 2 million tonnes of water for each tonne of lithium)
- Cobalt and nickel mining in countries with low regard to environmental and human safety
- The large physical footprint of renewable projects impacts on other land use, in particular farming.
  - Might be possible in Australia but not for many countries

https://www.rainforestreserves.org.au/impacts-of-largescale-renewables

https://dialogue.earth/en/nature/in-argentina-lithium-mining-leaves-a-river-running-dry/

3. The System Context & The System Boundary (1)

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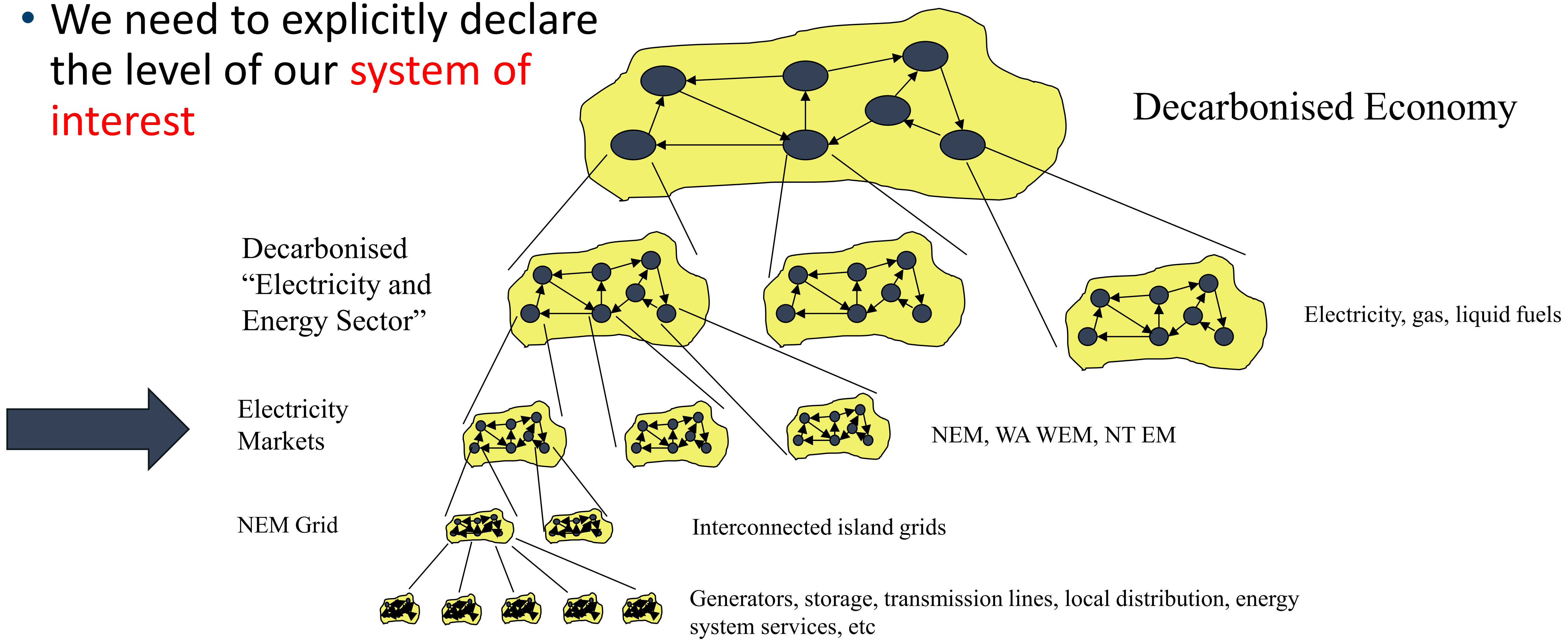
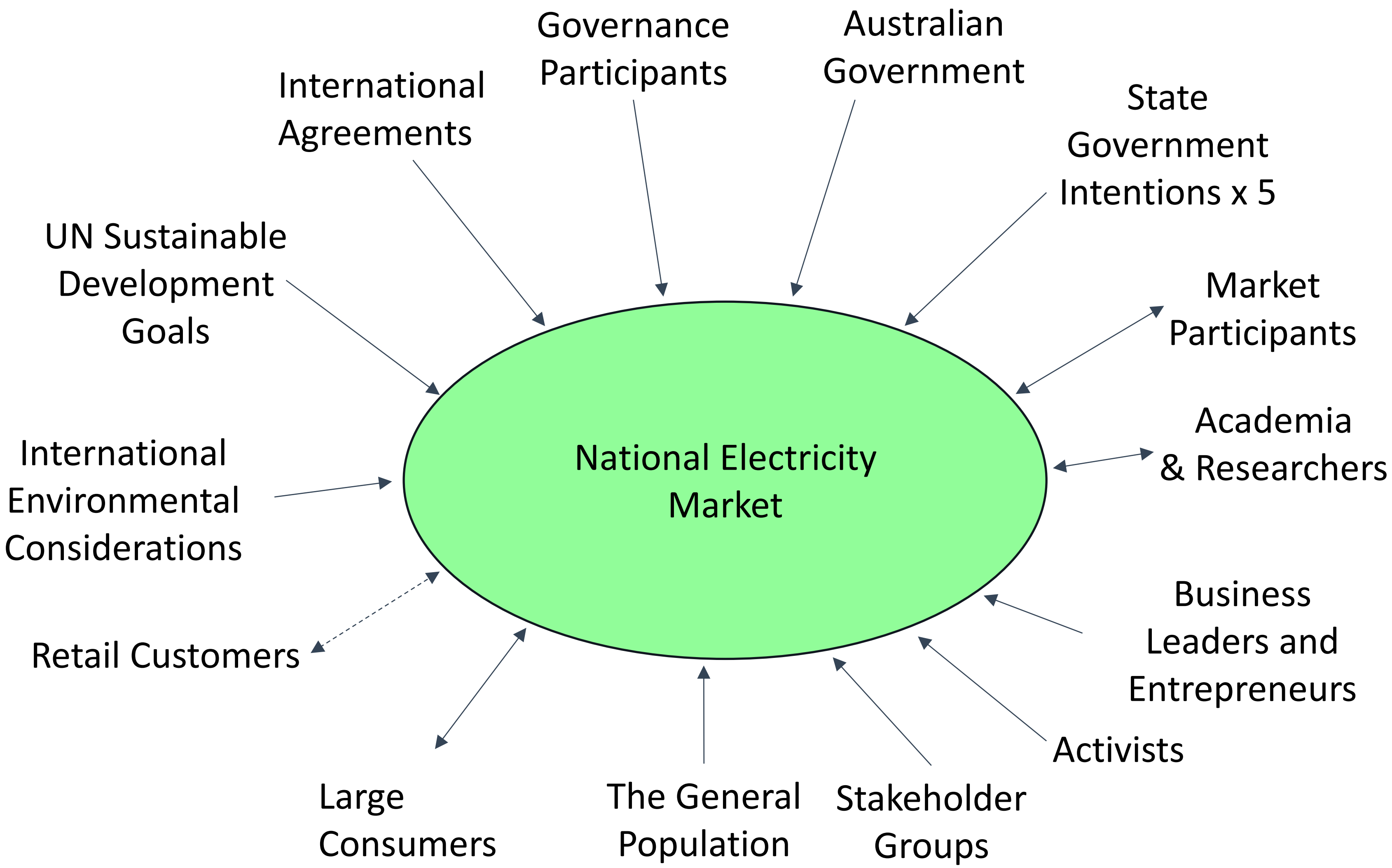
- We need to explicitly declare the level of our system of interest



The System Context & The System Boundary (2)

- The system has to be the NEM
- Large number of participants and influencers
- Significant constraints
- The external interfaces are primarily soft and ideologically driven
- Sometimes we forget that the context is also bounded by physics and electrical engineering realities.



4. Primary and Secondary Issue Identification

- SDG 7 - Ensure access to affordable, reliable, sustainable energy
- Secondary Issues: Need to balance action on SDGs:
  - Climate action
  - Sustainable cities and communities
  - Decent work and economic growth
  - No poverty
  - Industry, innovation and infrastructure
  - Reduced inequalities
  - Responsible consumption
  - Life on land

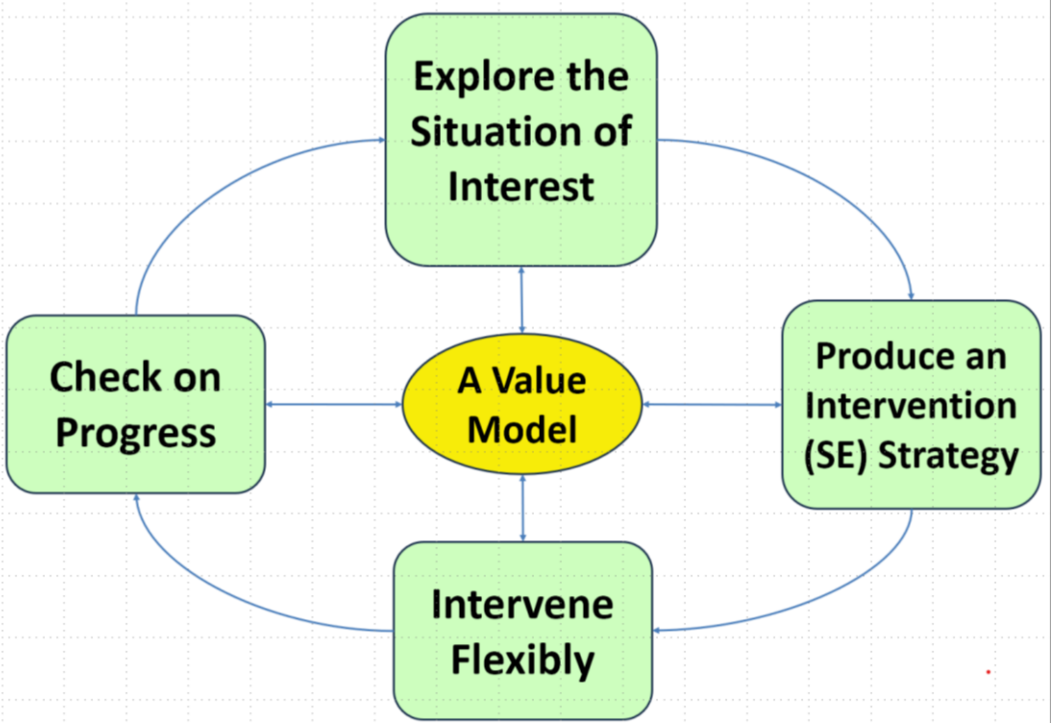
United Nations Sustainable Development Goals: https://sdgs.un.org/goals

5. Value Model

- Need to determine what “good” looks like
- It is normal to define this using a few high-level metrics
- These can be combined into an objective function
- Value models tend to be enduring but can be subjected to change particularly as societal norms evolve

Value Model Drivers

- More than just Climate Action (13) & Clean Energy (part of 7)
- Proposed value model foci: (UN Goals)
  - AEMO/NEM requirements (7)
    - Outage minutes per year
    - Resilience and technical attributes
    - Restoration
  - Decarbonisation (13)
  - Affordable power (7)(1)
  - Decent Work and Economic Growth (8)(1)(9)(3)
  - Environment (11)(12)(14)(15)(3)



United Nations Sustainable Development Goals: https://sdgs.un.org/goals

Possible Attributes for a Value Model for the NEM What matters to you?

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- Net-zero – CO_2 emissions
- Cost of electricity – affordability
- Privacy
- Sovereignty and restoration of industrial capacity
- Maintenance of Australia’s standard of living
- Availability, reliability, resilience, etc
- Rate of decarbonisation of the economy
- Enablement of economic growth
- Real environmental outcomes: sustainability, circular economy, minimising damage to the planet
- Decent work – including in the supply chain outside of Australia
- Feasibility: a viable solution across multiple dimensions

6. Classifying the System of Interest & Its SE Impact

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Dimension	Categories	SE Impact
Complexity	**Chaotic** e.g., global political-economic system but also some simple systems like an articulated pendulum whose trajectory cannot be predicted.	Not manageable but trajectory can be influenced and regulated to an extent. Use complex systems approaches from management science, INCOSE Complexity Primer.
	Complex e.g., most things involving numbers of humans: organisations, governments, but also the Internet, etc.	Use SoSE or iterative SE approaches together with broader organisational improvement approaches that can deal with continual change. Use complex systems approaches from management science, INCOSE Complexity Primer.
	Complicated or **Simple** e.g., the design of an unprecedented system or a product.	Use conventional best practice SE approaches.
Degree of Human Involvement	**Substantial**: humans are a substantial part of system, e.g. an entertainment system, global IT, and phone services.	Multi-methodological approach: SE with a soft systems methodology and market research.
	Humans needed to operate the system, e.g., an aircraft, power plant, etc.	Use conventional systems engineering.
	Little human engagement, e.g. an autonomous vehicle.	Use, conventional systems engineering or incremental development as needed.
Degree of Stakeholder Agreement	**Pluralist** or **coercive**: stakeholders have divergent worldviews and accommodation on ways forward needs to be established.	Will require interpretive soft systems approaches to appreciate and deal with the various viewpoints and lack of alignment together with SE to deliver technical components of the solution.
	Unitary problem situation: all stakeholders have a common view of a good outcome.	Contemporary SE should work well.
Level of the System of Interest These are aligned with Hitchins levels: systems.hitchins.net/systems/world-class-systems-enginee.html	**Levels 3,4 & 5** - Enterprise-level systems, military task force, civilian infrastructure, etc.	These systems tend to be enduring and evolve through multiple, asynchoronous projects - use System of Systems Engineering (SoSE).
	Level 2 - Large systems such as ships, aircraft, buildings, IT systems, etc.	Use contemporary systems engineering.
	Level 1 - Products, e.g., a computer, a crane, a heat exchanger, etc.	Use discipline-based product engineering with selected SE extensions.

Dimension	Categories	SE impact
Connectivity	**Very High**, e.g., large cloud-based service system with thousands of nodes.	These systems tend to be enduring and evolve through multiple projects - use SoSE and continuous iterative development for constituent systems.
	High to **Low** - elements connected via open networks with user numbers in the hundreds, e.g. command and control system for military or emergency services, ambulance dispatch systems, etc.	SE or SoSE depending on the governance model. When ongoing development is expected, use continuous iterative development for software components.
System lifetime	**Greater than 30 years**	SoSE and SE with strong support system design and management.
	Greater than 5 years	Product Engineering or SE.
	Up to 2 years	Lightweight SE or product engineering.
Dynamicity	**Fast**: systems need evolving faster than system elements, e.g., market-driven IT services like phone apps, streaming services.	Use incremental SoSE approaches that can inherently deal with fast technology refreshes. Use continuous iterative development for software components, eg, Agile systems and software development approaches for constituent systems. Avoid the prescriptive, pre-specification paradigm.
	Moderate: systems and their components have similar rates of change, e.g., electricity generation and distribution.	SoSE approaches with aligned constituent systems SE approaches. Agile approaches are helpful here.
	Low: system changing slowly compared with system elements, e.g., most civil infrastructure.	Contemporary SE for whole system or product engineering depending on scale.
Governance	**Directed:** Single authority driving development and operations.	Contemporary SE or Directed SoSE as appropriate.
	Acknowledged: Modest central project and engineering effort – development projects managed separately.	Use Acknowledged SoSE approaches.
	Collaborative: Agreement that constituent system should be developed to work together.	Use Collaborative SoSE approaches.

Adapted from Adelaide University course materials in Complex Systems Engineering and Cook & Pratt (2016).

6. Classification of the SoI

- The NEM is a complex, continually-evolving, enterprise SoS
  - Defn: A SoS is a set of systems or system elements that interact to provide a unique capability that none of the constituent systems can accomplish on its own (SEBoK from ISO/IEC/IEEE 21389:2019). SoS are characterised by operational and managerial independence of constituent systems.
  - In operation it can be categorized a ***Directed SoS*** with AEMO providing highly-effective operational management
- AEMO describes the Optimal Development Path to a net-zero grid (AEMO, 2024) but:
  - AEMO has **no power to implement** such plans – mostly up to the market
  - Hence, the development and evolution of the NEM is more like a ***Collaborative or Acknowledged SoS*** with occasional Directed aspects

Selection of Systems Approaches

- The SoI classification indicates a SoS methodology is required.
- SEBoK describes a list of SoS methodologies: https://sebokwiki.org/wiki/Systems_Engineering_for_Systems_of_Systems
- The best suited SoS methodology would be SoS Governance

> *SoSG, through its origins in complexity theory, seeks to expand SoSE away from the "technology first and technology only" perspective of earlier versions of SoSE. It includes appreciating the context to determine what initiatives might be feasible; identifying areas that can improve the SoS; and adopting a "long-term view" of the evolutionary development of the SoS. SoSG appreciates that de-centralized control can be expected and is suited to a wide range of collaborative and acknowledged SoS challenges.*
>
> Keating et al. (2018), Cook & Unewisse (2017)

- The Wave Model would also be useful to architect the ongoing technical solution and driving incremental improvements.

SoSE Approach	Description
Enhanced Traditional Systems Engineering (ETSE)	ETSE applies traditional top-down systems engineering at the level of a portfolio of projects by adapting systems engineering processes and using architecture frameworks to represent the artefacts. Ideal for centralized, directed SoS management in a slowly changing environment. Key references: Levis and Wagenhals, (2000), USN, (2006 a&b).
Complex Systems Engineering (CSE)	CSE is based on complexity theory and strongly advocates that the top-down ETSE approach is not well suited to SoSE because it cannot handle the complexity of SoS and because the preconditions for TSE to be successful are not evident in SoS. CSE changes the focus from "…here is the solution designed from the requirements, now go implement it…" to "…here are the selective pressures acting on the elements present, now resolve or reduce them…" Ideal for rapidly integrating SoS from pre-existing Constituent Systems (CS) where little centralized control exists. Key reference: Bar-Yam, (2003); Norman and Kuras, (2006).
Dynamic Optimization of SOS using Value Measurement (DOSVM)	DOSVM draws on complexity theory and recognizes that it is the Constituent System Project Offices (CSPO) that have the resources and means to change, and that in many SoS, the actual authority and resources of any central element are never going to be sufficient to do more than guide the evolution of the SoS. In DOSVM, each CSPO views the SoS in terms of its utility to itself, seeking to "optimize" the SoS (from its point of view) through the influences available to it. DOSVM is ideal for collaborative SoS in which there is little or no central control. Key references: Honour (2016), Honour and Browning, (2007).
SoS Governance (SoSG)	SoSG, through its origins in complexity theory, seeks to expand SoSE away from the "technology first and technology only" perspective of earlier versions of SoSE. It includes appreciating the context to determine what initiatives might be feasible; identifying areas that can improve the SoS; and adopting a "long-term view" of the evolutionary development of the SoS. SoSG appreciates that de-centralized control can be expected and is suited to a wide range of collaborative and acknowledged SoS challenges. Key references: Keating (2015), Morris et al. (2006).
US Department of Defence SE for SoS: The Wave Model	The wave model is an evolutionary model that comprises five main process elements that incorporate experiential learning from many SoSE programs. It was originally designed for acknowledged SoS that have a small SoSE team but has also been applied to collaborative SoS challenges. It is a meta-methodology, i.e. one that guides the design of SoSE methodologies and is extensively documented. The wave model is widely applicable and is tailorable to the expected Australian Program level of SoSE effort. Key references: DoD, (2008), Dahmann et al (2011), Lane et al. (2010) & Dahmann and Heilmann (2012).
US Navy Mission Engineering Approach	Mission engineering arose to support the assessment of naval systems and capabilities through a SoS approach to analyze the impact of making naval investments across the diverse domains of surface, undersea, air, land, and networks as well as maritime coalition force integration. Mission engineering assessments are executed following a systematic, quantifiable, and iterative approach, which combines the structure of systems engineering (SE) and the tactical insights from operational planning. This approach incorporates a mission focus into integrated capability development. Note that mission engineering activities can be aligned to the elements of the wave model. Key references, Moreland (2015), TTCP (2016).
The British Systems Thinking Approach (BSTA)	BSTA embodies soft systems thinking, systems theory, social theory, and the pragmatism of problem solving to achieve shared meaning and objectives across the stakeholder group to deal with the social and technical aspects of SoS simultaneously. Key to the approach is the mapping of the SoS of interest onto more detailed SE approaches. The BSTA is the ideal approach for SoS problems where there is no obvious consensus of what represents a good SoS outcome trajectory and where the SoS is already established and running. It works well for a wide range of problem definition challenges within the CLC. It can be combined with other approaches. Key references: Checkland and Scholes (1990), Hitchins, (2007).
Systemic Strategic Planning and Execution (SSPE)	(SSPE) is a comprehensive but austere multi-methodology inspired firstly by strategic planning, systems theory and BSTA to achieve inclusivity and stakeholder engagement in a systemic way and secondly by ideas from system engineering to achieve structured abstraction and trade-offs between candidate force structures. SSPE is ideally suited to force design and has been used successfully in Australia; it needs to be enhanced with additional technical approaches to cover technical integration aspects. References: Hodge and Cook (2014a, b &c).
The United Kingdom Ministry of Defence (MOD) System of Systems Approach (SOSA)	(SOSA) is a way of working that spans the entire capability and systems acquisition cycle to deliver capability that provides assurance that effective, coherent, interoperable, re-useable and cost-effective systems and equipment are acquired. SOSA does this by bringing to bear a range of proven reference models, analytical tools, methods and techniques based on SE to generate the evidence to inform decision-making throughout the acquisition cycle. SoSA covers the needs well and would be a good aspirational goal. Key reference: Coffield (2016).

Conclusion (1)

INCOSE

- The first stage of the EPIC+ cycle has surfaced the breadth of issues that need to be considered when evolving a large-scale, socio-technical system.
- Given the breadth of knowledge and competencies needed to tackle complex systems problems, there is a need for an intelligent assistant to guide SEs through the EPIC+ process and the selection and implementation of systems practices.
- The information contained in the *Tradecraft Guide* is the first step in this direction and has proven effective in this example.
  - It has identified SoS Governance and the Wave Model as appropriate systems methodologies.
  - It can be used to identify lower-level methods and techniques

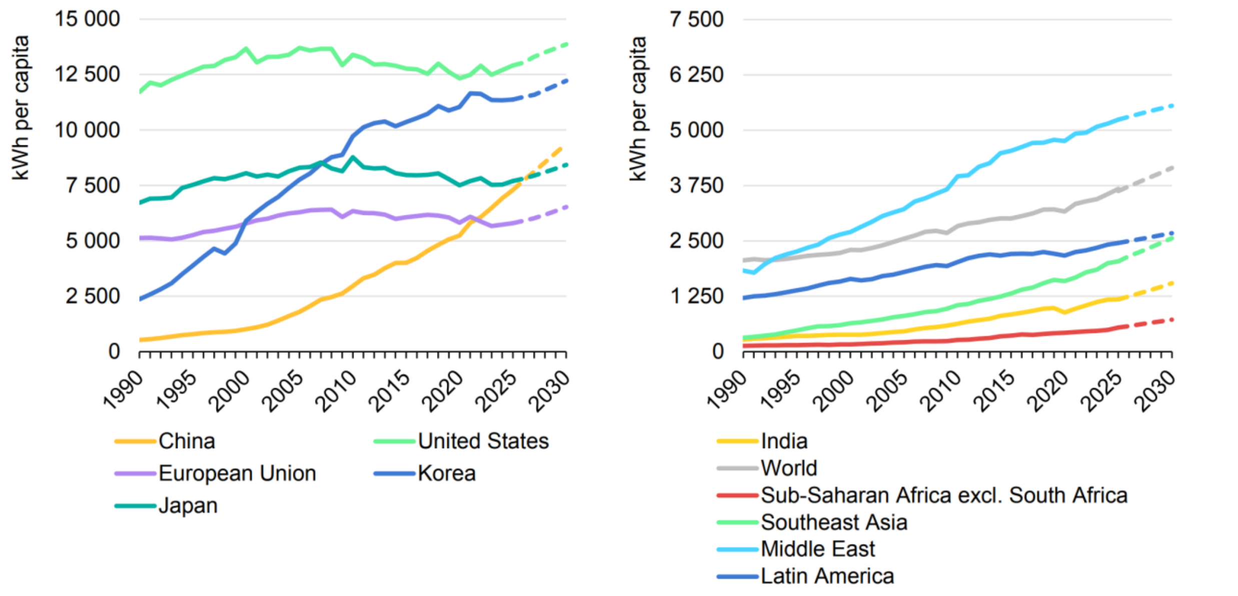
Conclusion (2)

- The whole-of-system exploration of the Australian NEM has surfaced many useful insights
  - Energy system evolution must be driven by a set of suitably weighted measures not just CO_2 reduction
  - The narrow media/public focus needs to shift from electricity ***generation*** to end-to-end ***grid*** and ***market*** considerations.
  - Cost cannot be ignored or waved away because it impacts millions of people, the nation's economy and international competitiveness, living standards, etc
  - Lifecycle costing is needed to make sound decisions. This needs to include the remediation and recycling of all infrastructure – escrow?
  - Environmental issues need much more holistic treatment
    - Need to determine what a good environmental outcome looks like
    - Need to balance the value of CO_2 emission reduction against the environmental costs of achieving the reduction
    - Environmental issues are inherently global in nature and thus trade studies need to consider global environmental impact
    - Input materials are finite – need to consider consumption of materials when making decisions
    - Decide what do we mean by "Sustainable"?
- Could you have learned about the nature of the problem just by "reading-in"?

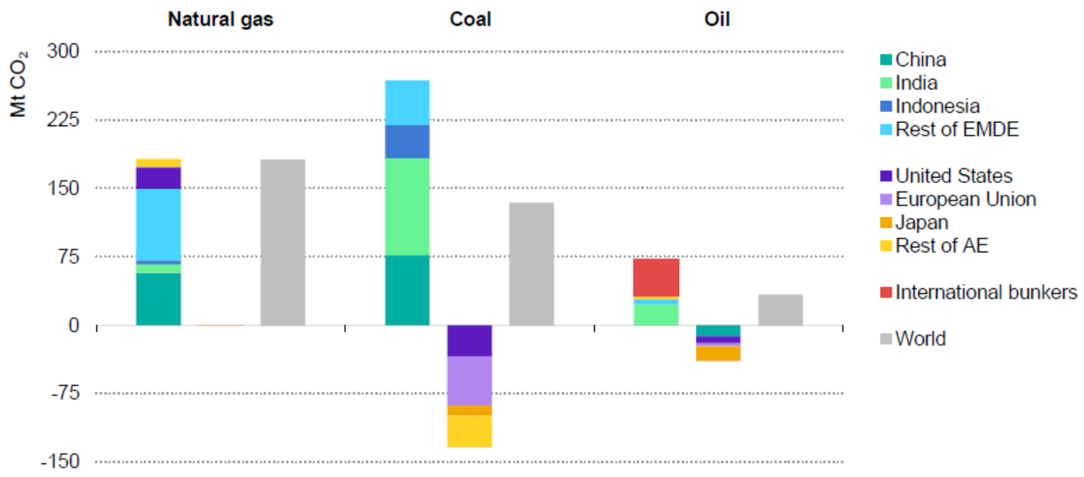
Afterword - Global Energy Trends
(IEA, 2026)

- Overall energy demand is rapidly rising
- Hydrocarbon use stable
- CO_2 emissions continue to increase despite reductions in advanced economies
- Global issues require all nations to buy into global solutions

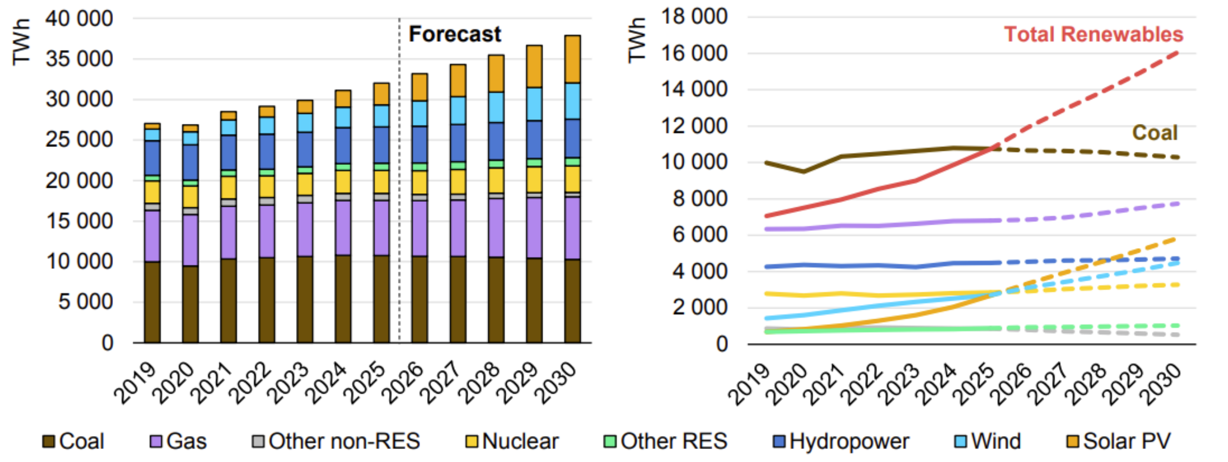
Electricity consumption per capita in selected countries and regions, 1990-2030



Change in CO_2 emissions from combustion by fuel and region, 2023-2024



Global electricity generation by source, 2019-2030



Aligned with the INCOSE Vision 2035

- The concepts behind the Tradecraft Guide are not new; they are maturing from the increasingly application of SE to complex socio-technical contexts
- This drives the need for broad competencies and knowledge of meta-methodologies

Systems Engineers have a duty of care to address the broader impact of their systems on society and the environment

Systems Engineers should also speak up when they encounter feasibility or risk issues in the wider systems context

Questions?

References

- AEMO, 2020. *Power System Requirements*. AEMO.
- AEMO, 2024. *2024 Integrated Systems Plan for the NEM*, AEMO.
- Briggs, C. 2024. “Australia needs tradies and materials to build the power grid of the future.” *The Conversation,* 3 Sept 2024.
- Cook S.C. & Pratt J.M., 2016. “Typology dimensions for classifying SoSE problem spaces,” *11th IEEE System of Systems Engineering Conference (SoSE)*, Kongsberg, Norway.
- Cook S. C. & Unewisse M. H., 2017. “A SoS Approach for Engineering Capability Programs”, *INCOSE International Symposium 2017.*
- DCCEEW, 2025. *Australia’s Net Zero Plan,* Department of Climate Change, Energy, the Environment and Water, Commonwealth of Australia.
- IEA, 2022. *Nuclear Power and Secure Energy Transitions*, IEA.
- IEA, 2025. *Global Energy Review*, IEA
- IEA, 2026. *Electricity 2026 Analysis and forecast to 2030.* International Energy Agency.
- INCOSE, 2021. *Systems Engineering Vision 2035*, INCOSE.
- Keating C. et al., 2015. “Systemic Intervention for Complex System Governance”, *INCOSE International Symposium 2018.*
- Hall, A. D. 1989. *Metasystems Methodology: A new Synthesis and Unification.* Pergamon Press.
- Hitchins, D.K. 2007. *Systems Engineering: A 21st Century Methodology.* Wiley.
- Jackson M. C., 2024. *Critical Systems Thinking – A Practitioner’s Guide*, Wiley.