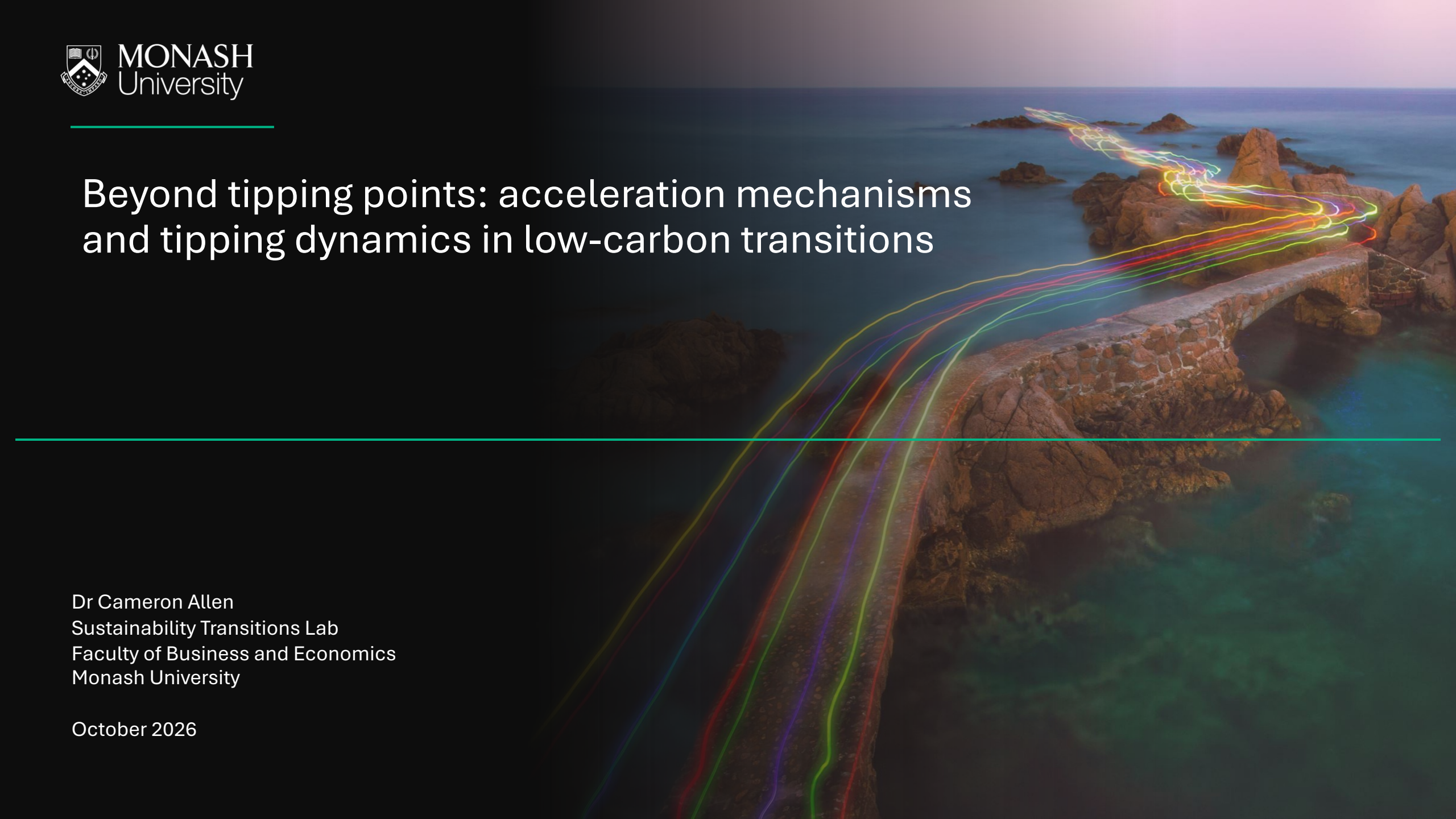
Beyond tipping points: acceleration mechanisms and tipping dynamics in low-carbon transitions



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October 2026

Sustainability Transitions Lab (STL)

An impact lab in Monash Business School (Melbourne, Australia)
Lead: Prof. Rob Raven

Our transition domains

Circular economy

Transforming production and consumption systems



Climate-safe

Accelerating transitions to net-zero emissions and climate resilience



Nature-positive

Halting biodiversity loss and restoring ecosystems



Our research capabilities

Understanding transitions

Enabling transitions

Accelerating transitions

Acceleration and tipping points – transitions perspective

- **‘Acceleration’ in transitions research** – traditionally a ‘phase’ in which transitions cross a tipping point and shift from incremental emergence to rapid diffusion
- **Recent interpretations:**
  - a ‘**sustained increase in the pace of change**’ (Sovacool et al., 2025)
  - Differentiate ‘**acceleration phase**’ (short, growth pulses) and ‘**steady growth phase**’ (sustained rate) (Jewell et al, 2026)

- **Empirical research** is uncovering **feedback mechanisms** associated tipping points and acceleration
  - **Positive tipping points** -> self-reinforcing techno-economic feedbacks (e.g. Sharpe and Lenton, 2021; Strauch, 2020)
  - **Socio-technical perspective** –> socio-political feedbacks, -ve feedbacks, ‘tipping dynamics’(e.g. Ayoub and Geels, 2024)
  - **Systems perspective** -> dynamic reinforcing/balancing feedbacks, ‘growth of new’ and ‘decline of old’ (Allen et al, 2023, 2026)

- **Knowledge gaps:**
  - **Conceptual issues** – what is tipping/accelerating? Which dimensions? Technical components or whole systems?
  - **Mechanisms of acceleration/tipping** – types of feedbacks, causal structure, sequencing, combined effects
  - **From technical components to whole systems to net zero transitions** - How does acceleration spread within and across multiple systems?

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Special collection on accelerating sustainability transformations



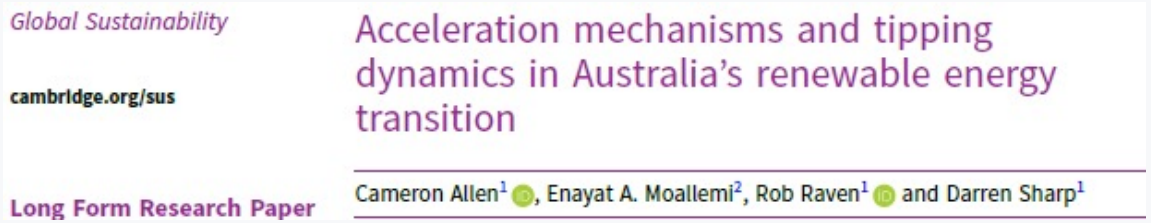
Editors:
Cameron Allen, Monash University
Frank Geels, University of Manchester
Per Olsson, Stockholm Resilience Centre

11 new studies on acceleration - emerging insights:

1. Acceleration is **not a smooth or inevitable process – 'tipping dynamics' rather than single 'points' and S-curves**
2. Acceleration emerges from multiple **interacting positive and negative feedbacks** across dimensions – change over time, context matters
3. Acceleration can be **deliberately enabled, sustained and restored** -> policy plays a crucial role
4. Acceleration involves both **building the new and weakening the old**
5. The goal is not simply faster change, but **faster and deeper change in the right direction -** speed should be considered alongside depth, direction, sufficiency, durability and justice

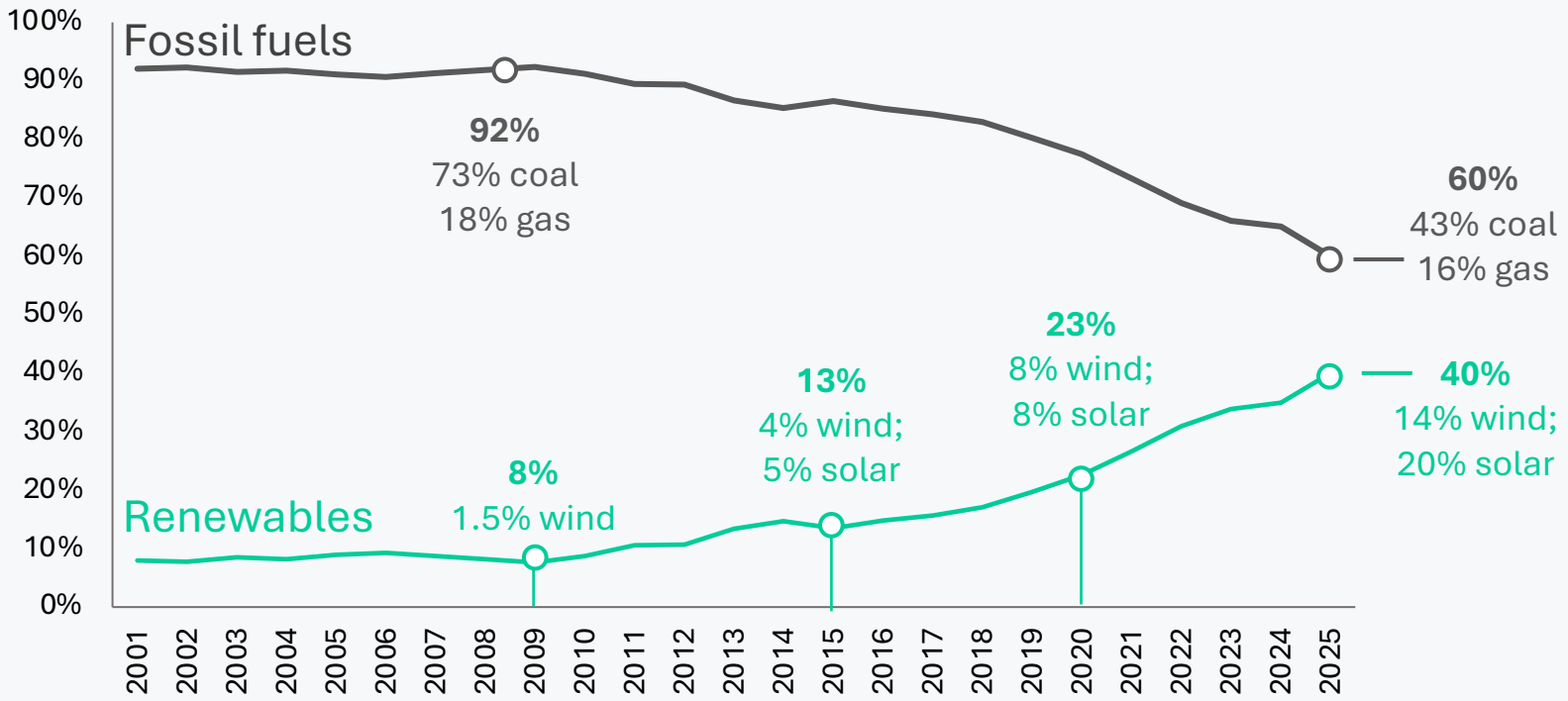
Special collection on accelerating sustainability transformations





https://doi.org/10.1017/sus.2026.10064

Australia’s electricity transition is accelerating through deployment of wind and solar (utility + rooftop)



~40% renewables by 2025

Wind and solar PV accounted for roughly 34% of total generation.

Rapid growth from ~2015

Large-scale wind and solar entered a rapid diffusion phase.

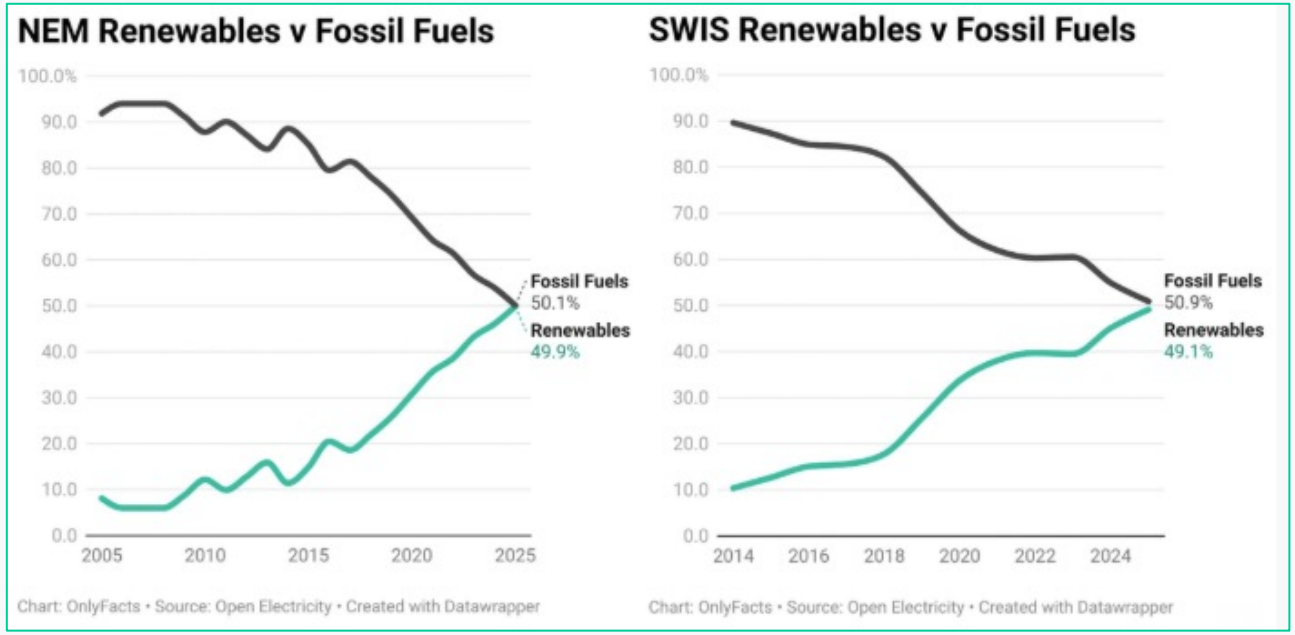
Further acceleration required

The 82% renewable electricity target for 2030 requires further acceleration.

Adoption of rooftop solar PV by households is world-leading (43% of households)

Acceleration in major electricity grids

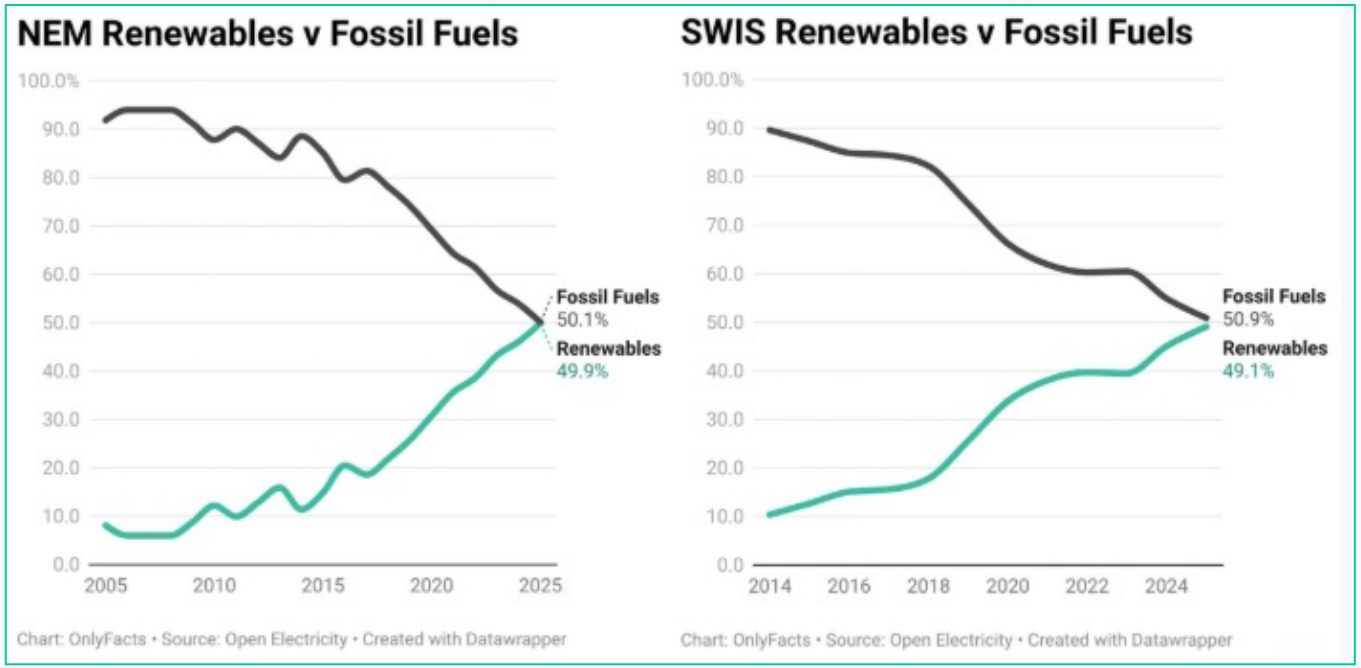
Renewables approached 50% of electricity generation in Australia's two largest grids (Spring 2025)



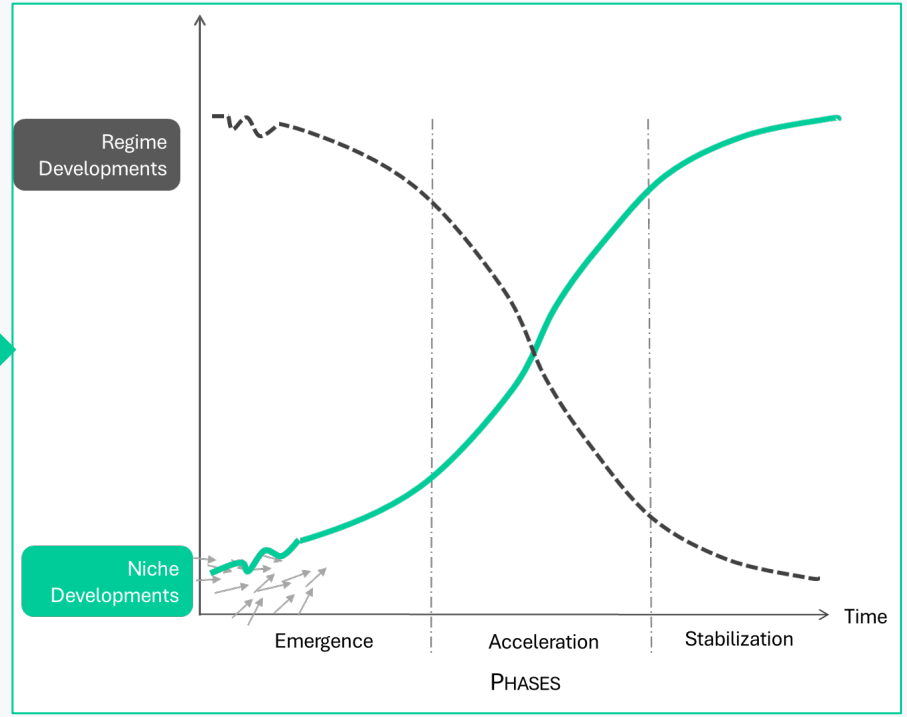
- **Tipping dynamics** or 'pulses' – policy-driven technology growth
- **Distinct pathways** in the Eastern and Western grids – similar overall trajectory
- Different generation mix (e.g. NEM includes hydro, more utility-scale); NEM spans several jurisdictions and greater policy uncertainty; NEM much larger; SWIS started later/more condensed

Australia case study – accelerating energy transition

*What explains the **'tipping dynamics' (acceleration/deceleration)** in renewable diffusion?*

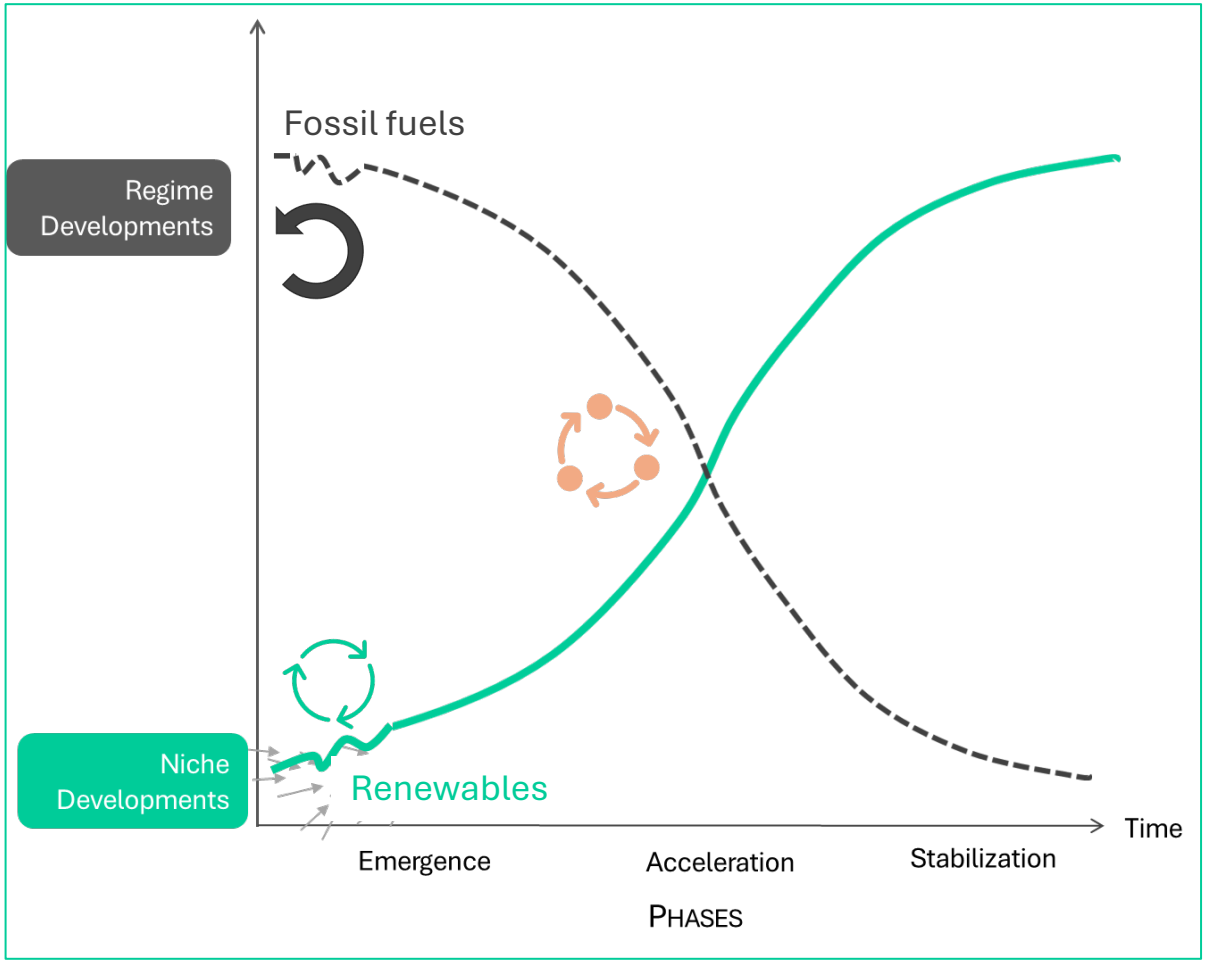


MLP + X-Curve Diffusion + System dynamics



Explaining acceleration and tipping dynamics

⇒ Conceptual proposition....



Three main 'types' of feedbacks shaping the pace of the energy transition that change in dominance over time:

Reinforcing niche acceleration

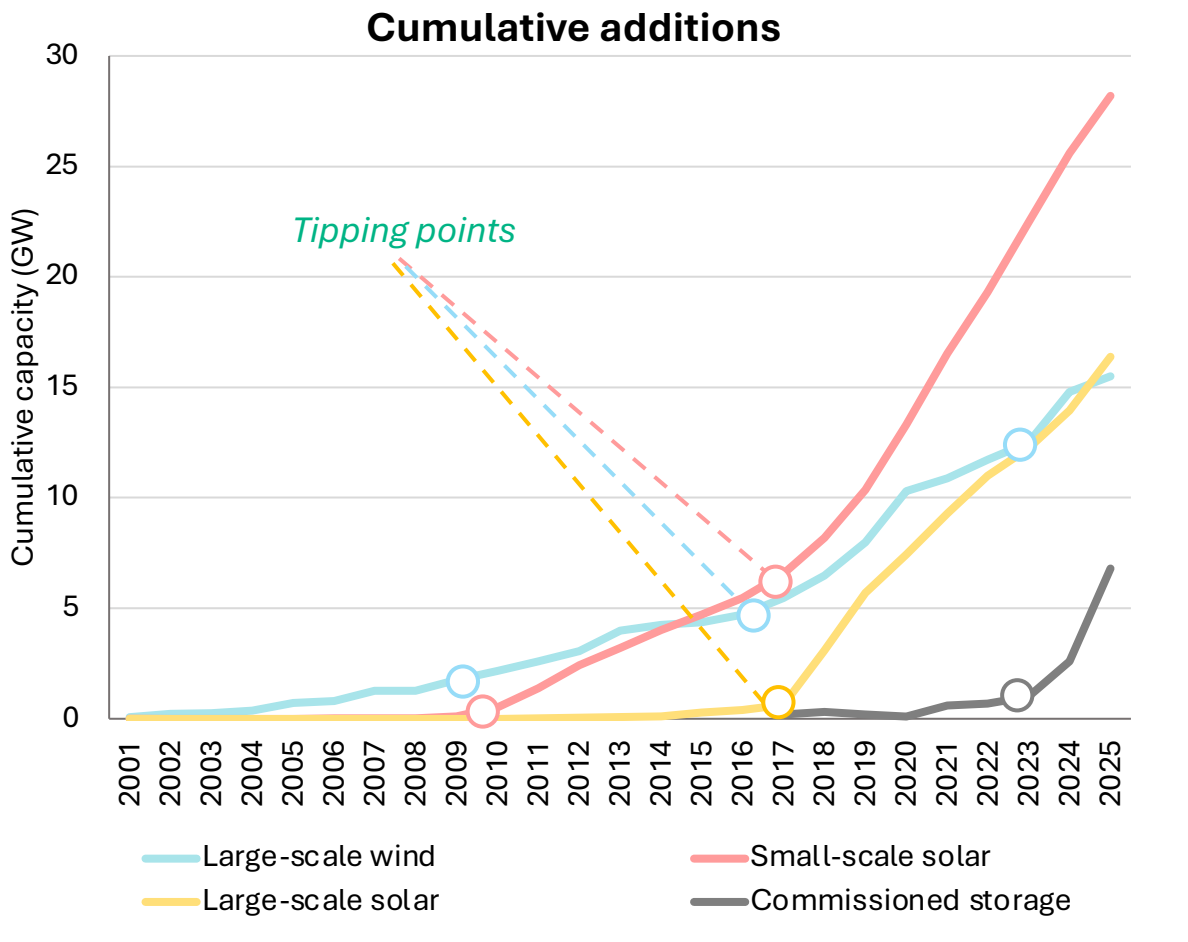
Stabilizing regimes / decelerating niches

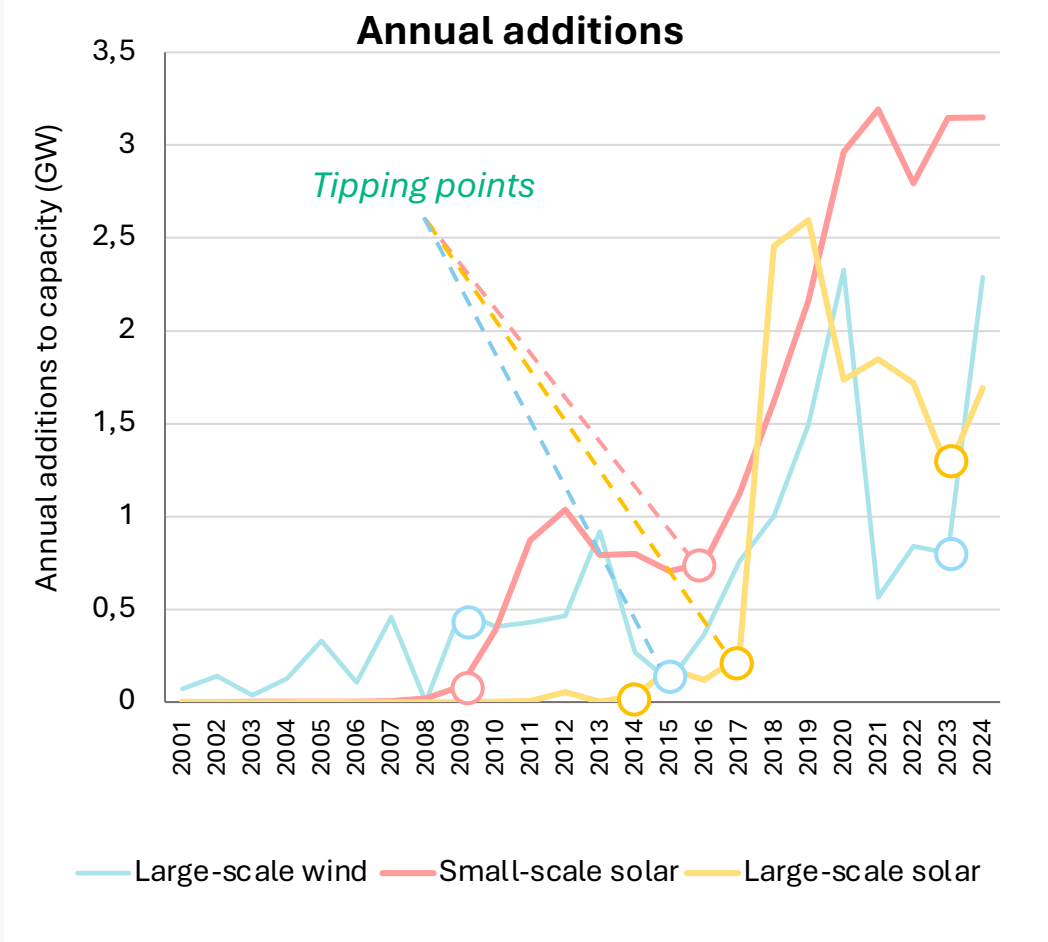
Reinforcing regime decline

Niche acceleration feedbacks: tipping in installed capacity and additions of wind and solar

Multiple ‘inflection’ points observed in diffusion data

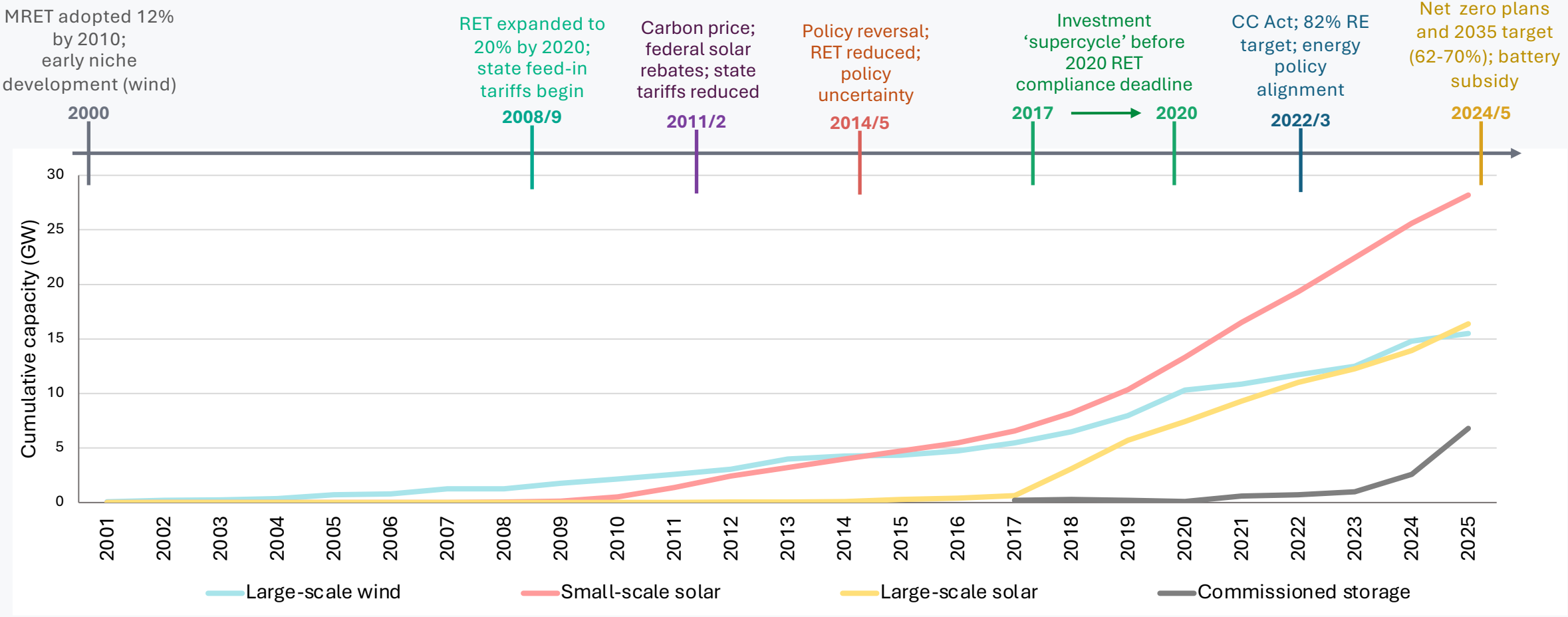
Define technology ‘tipping points’ where there is an inflection and spike in annual growth rate that persists across multiple years





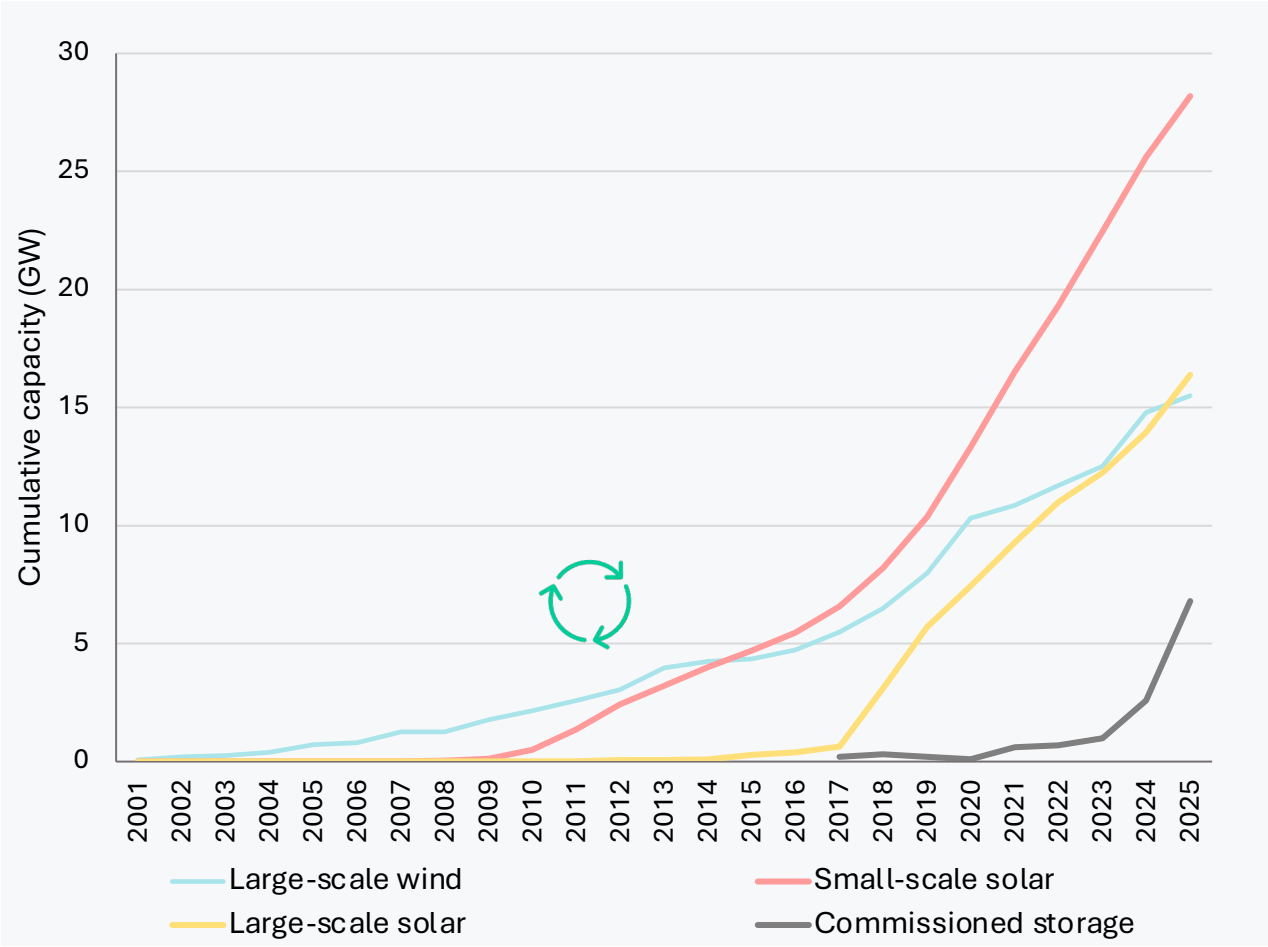
Niche acceleration I: policy created early markets & built momentum

Policies built conditions for self-reinforcing dynamics – catalysed early adoption, experience, learning, supportive constituencies…



Niche acceleration II: scale and learning feedbacks reinforced diffusion

By the 2010s, early policies strenghened techno-economic feedback mechanisms - made renewables more economically attractive and reinforced adoption



Techno-economic reinforcing feedbacks:

Learning-by-doing

Deployment improved design, installation and operational experience, increasing performance and attractiveness

Economies of scale

As demand and production scaled, unit costs decreased, further driving demand – rapid fall in wind/solar costs from 2010

Access to finance

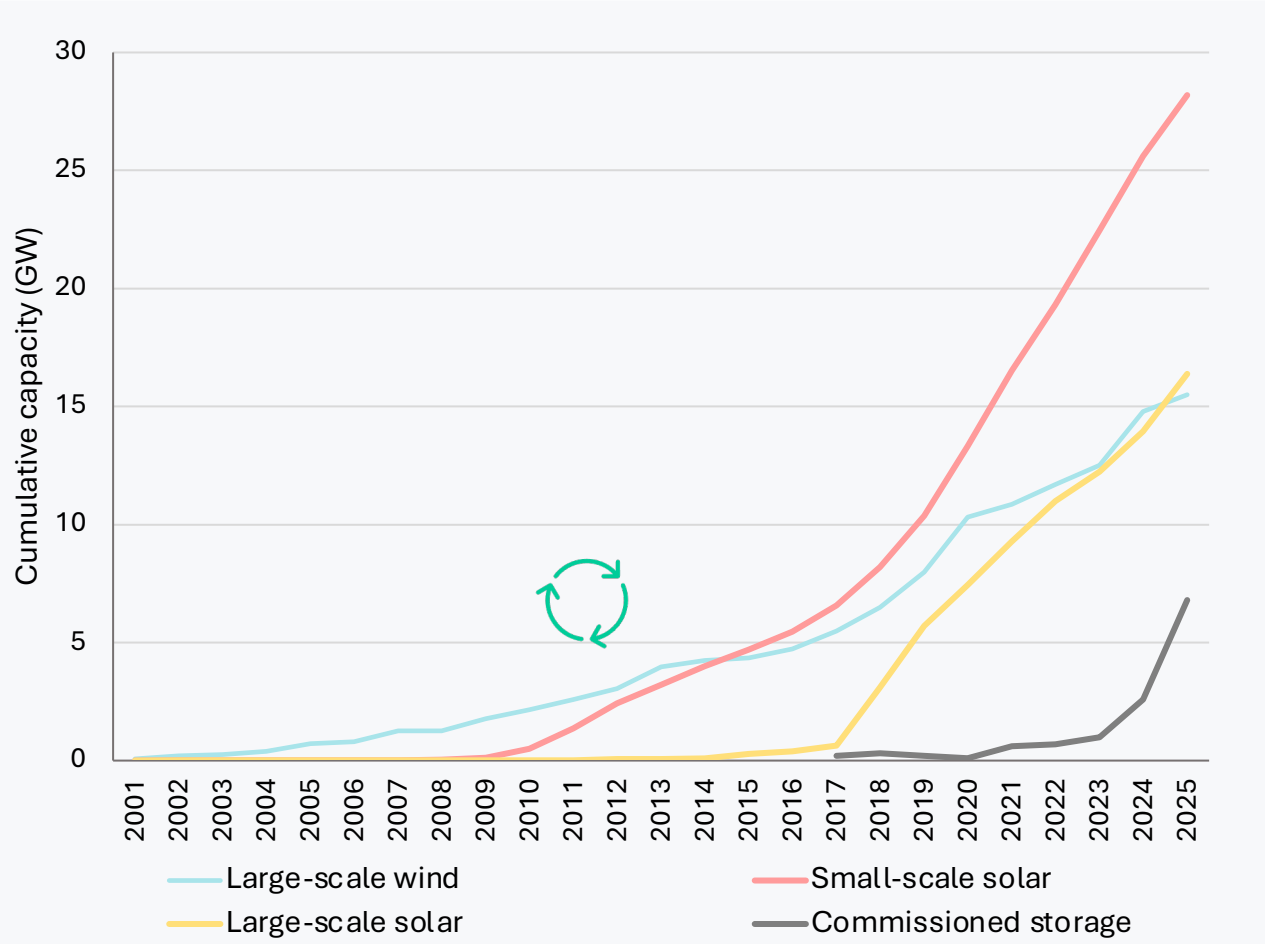
Growing adoption, revenues, and profitability of wind and solar PV firms enhanced investor confidence and stimulated investment

Complementary technologies/infrastructure

Deployment attracted complementary network upgrades, smart meters, storage etc., further reinforcing adoption

Niche acceleration III: social and policy feedbacks reinforced adoption

Not purely an economic story – as renewable deployment expanded, social and political dynamics interact with technology and market dynamics, reinforcing momentum



Policy and social reinforcing feedbacks:

Policy learning and increased ambition

Early successes, positive reviews, and experiential learning supported increase ambition and stronger policy support

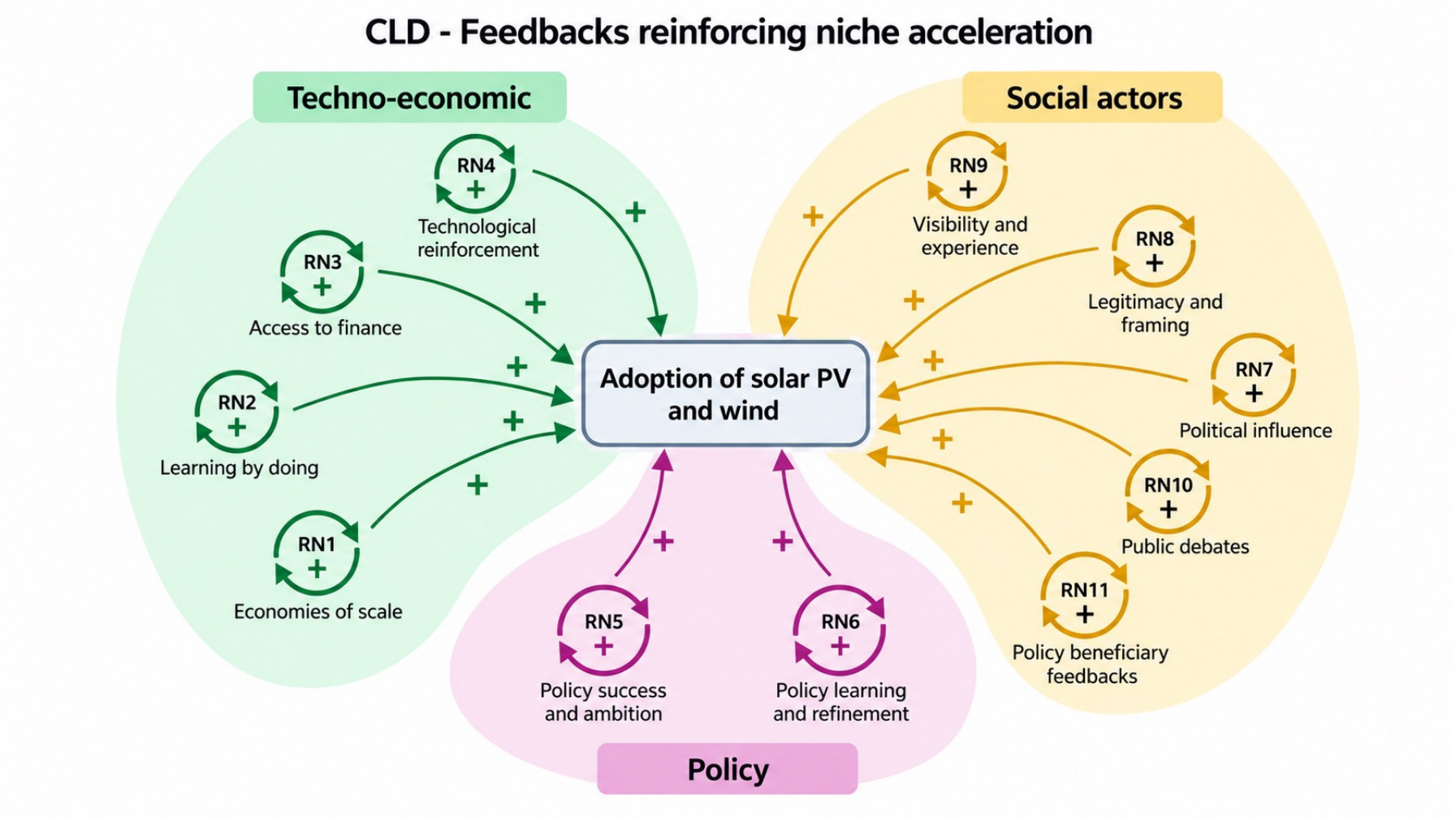
Political influence and legitimacy

Renewable lobbies and coalitions, advocates and public debates build political pressure for stronger policy

Visibility and beneficiaries

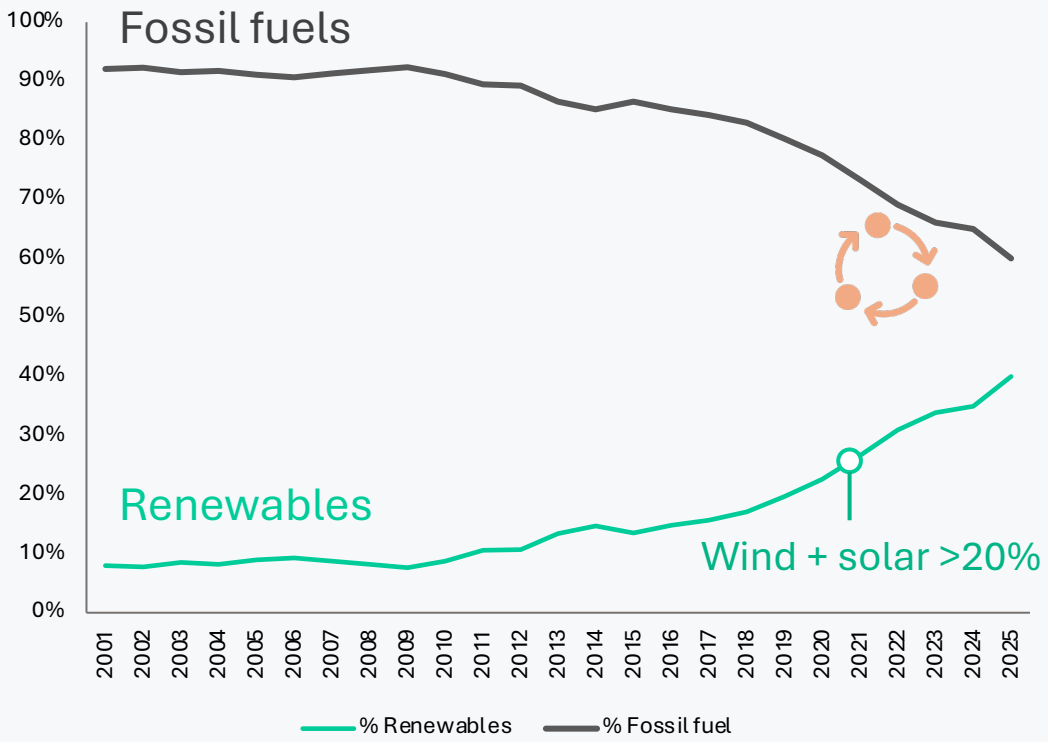
Visibility and positive experience promote adoption; subsidies create beneficiaries supporting policy

11 feedbacks reinforcing niche acceleration:



Feedbacks reinforcing regime decline

Regime decline became self-reinforcing after 2021, when solar/wind gained sufficient market share to affect coal demand, prices, profitability, finance and expectations



Regime decline reinforcing feedbacks

Diseconomies of scale, profitability and performance issues

Declining demand and revenues, reduced profitability and investor confidence, performance and reliability issues leading to stranded assets and early closures

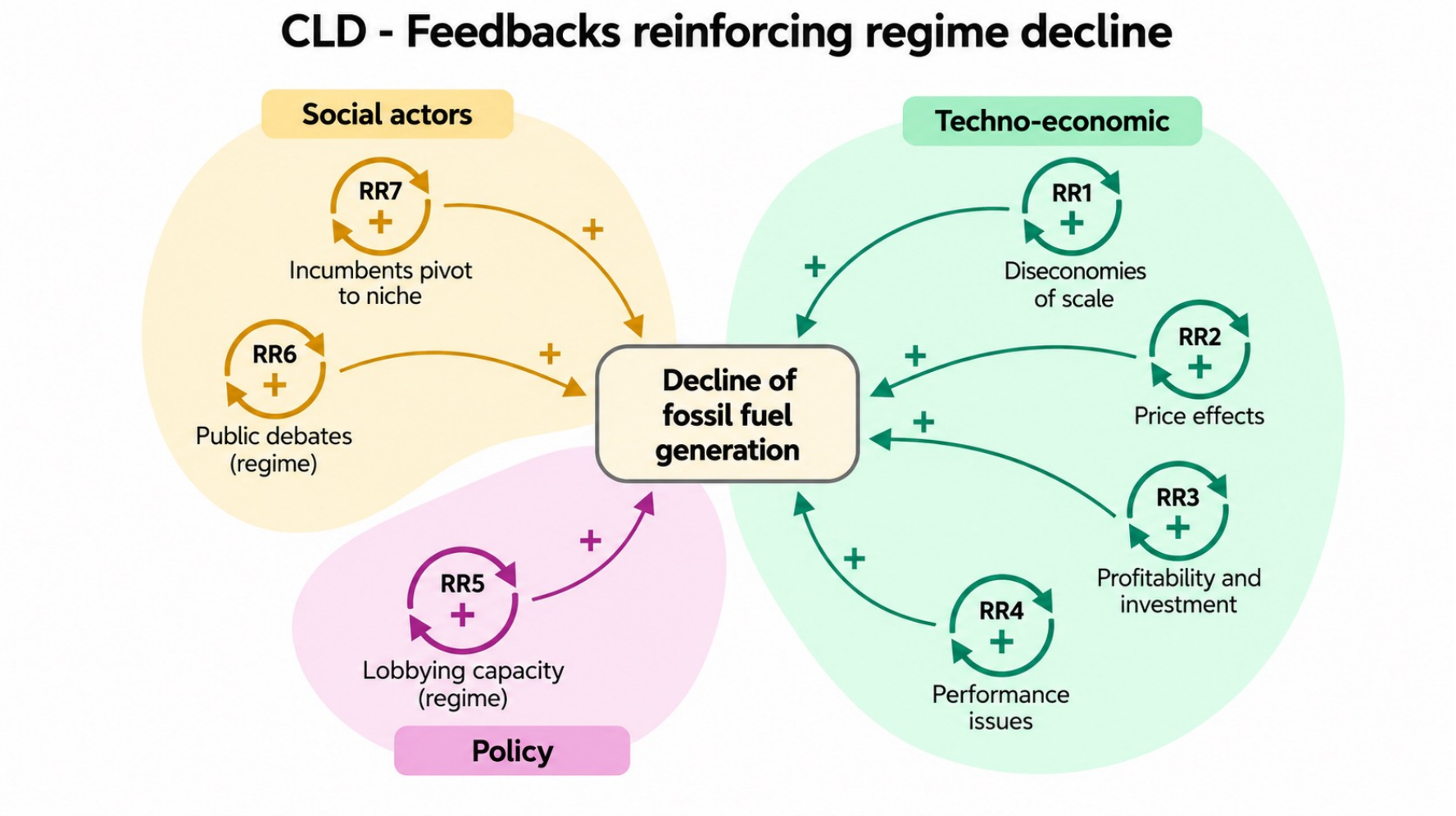
Declining legitimacy and weakening political influence

As market share declines and negative public debates strengthen about future of coal, so does ability of fossil industry to influence political debates

Incumbents pivot to niche

Incumbent utilities sets net zero plans from 2022, increasingly diversify away from fossil fuels towards renewables

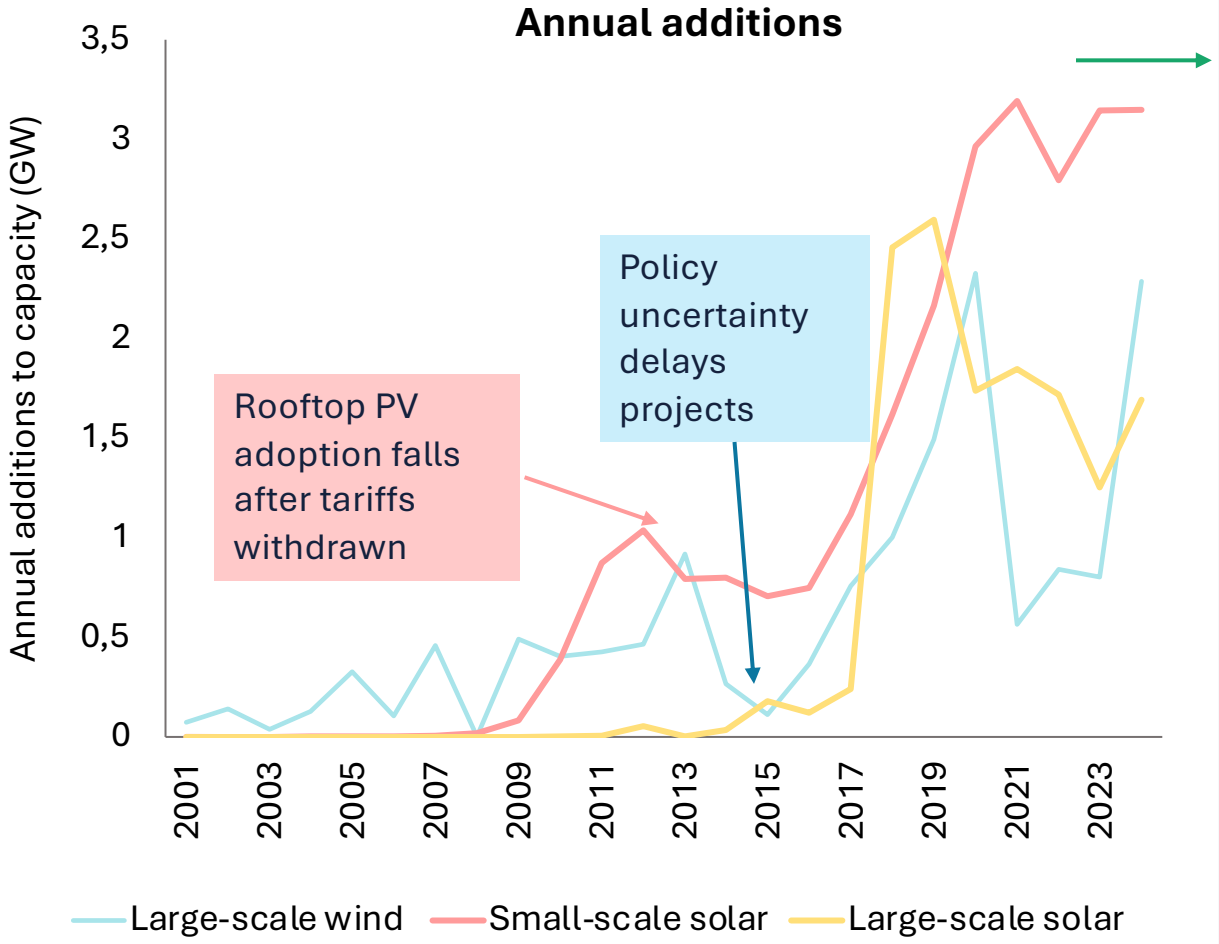
7 feedbacks reinforcing regime decline



Balancing feedbacks - regime stabilization / niche deceleration

Deployment oscillates between periods of acceleration and deceleration

Deceleration early on from policy withdrawals/uncertainty, and later from bottlenecks and backlash as transition gained pace



Additional bottlenecks and constraints have emerged since 2020:

Infrastructure and supply chain bottlenecks

Grid congestion, negative prices, connection delays, curtailment, supply chain issues, escalating project/technology costs and slow adoption

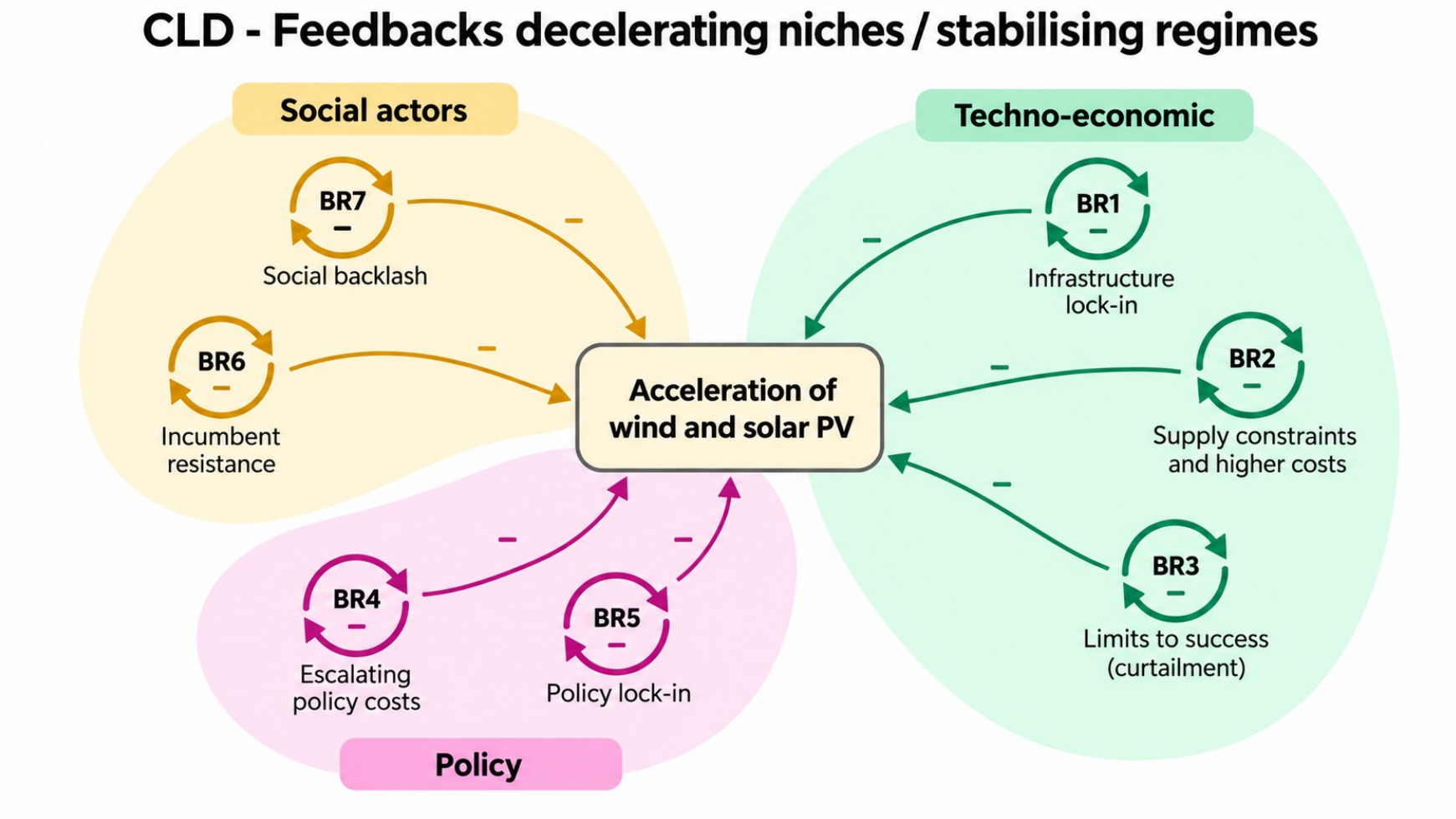
Institutional bottlenecks

Escalating policy costs, weak incentives and misalignment, regulatory delays discourage and delay investment

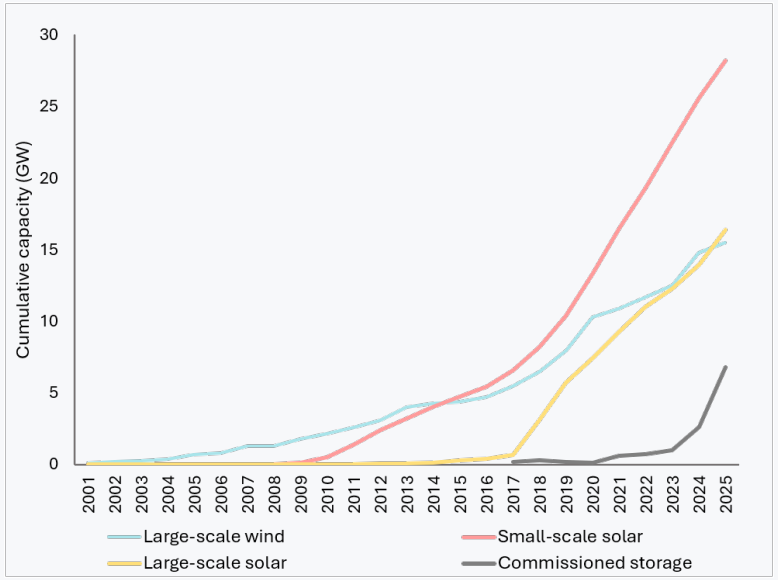
Social backlash and resistance

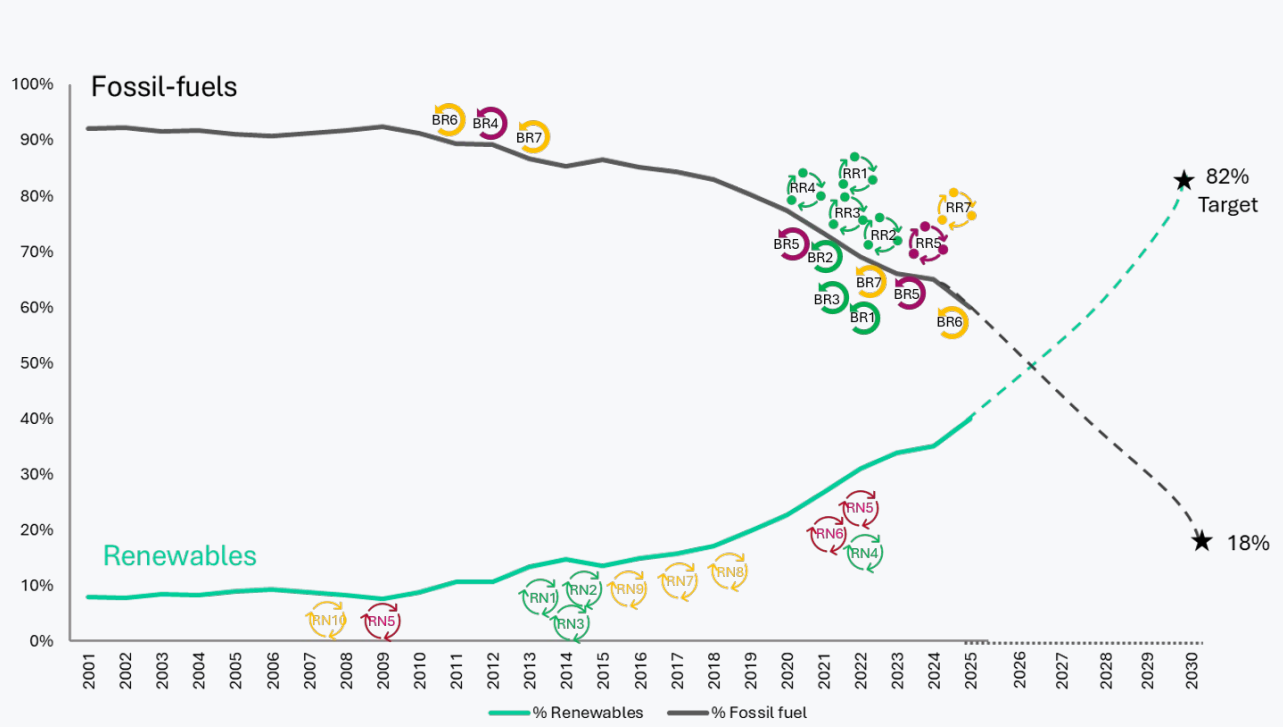
Community opposition, cost-of-living and distributional concerns and backlash periodically weaken public support; fierce lobbying by incumbent fossil fuel industry

7 balancing feedbacks decelerating the transition...



From technical components to whole-system transformation – net-zero electricity





- Clear evidence of acceleration and tipping dynamics in **technical components** (wind/solar)
- **Electricity system transformation -** resulting from interactions and alignment among **technologies, markets, institutions and social actors**
- Acceleration is a **dynamic and cumulative** outcome of feedbacks - rather than a single feedback mechanism or threshold
- Plotting feedbacks over time shows how they **strengthen/weaken** at different times – many emerging after system 'tipped'

Whole-system transformation – reinforcing niche acceleration

➢ Initial niche growth

Early public support and policies stimulate adoption, experience, learning

➢ Momentum/ acceleration

Cost reductions + coalitions + visibility + legitimacy reinforce

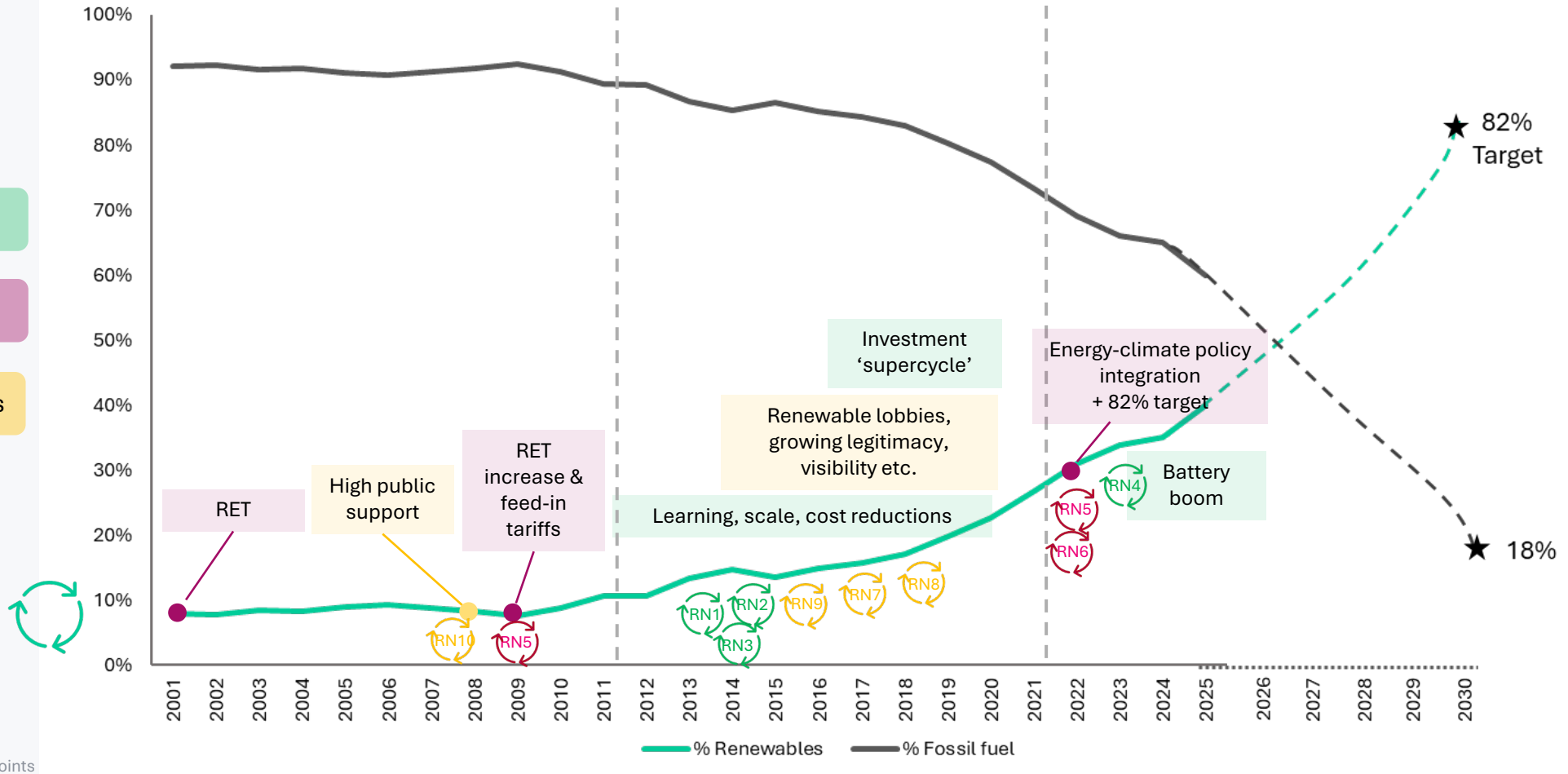
➢ Policy alignment and complementarity

Energy-climate policy integrated; increased policy ambition; complementary technologies

Technology

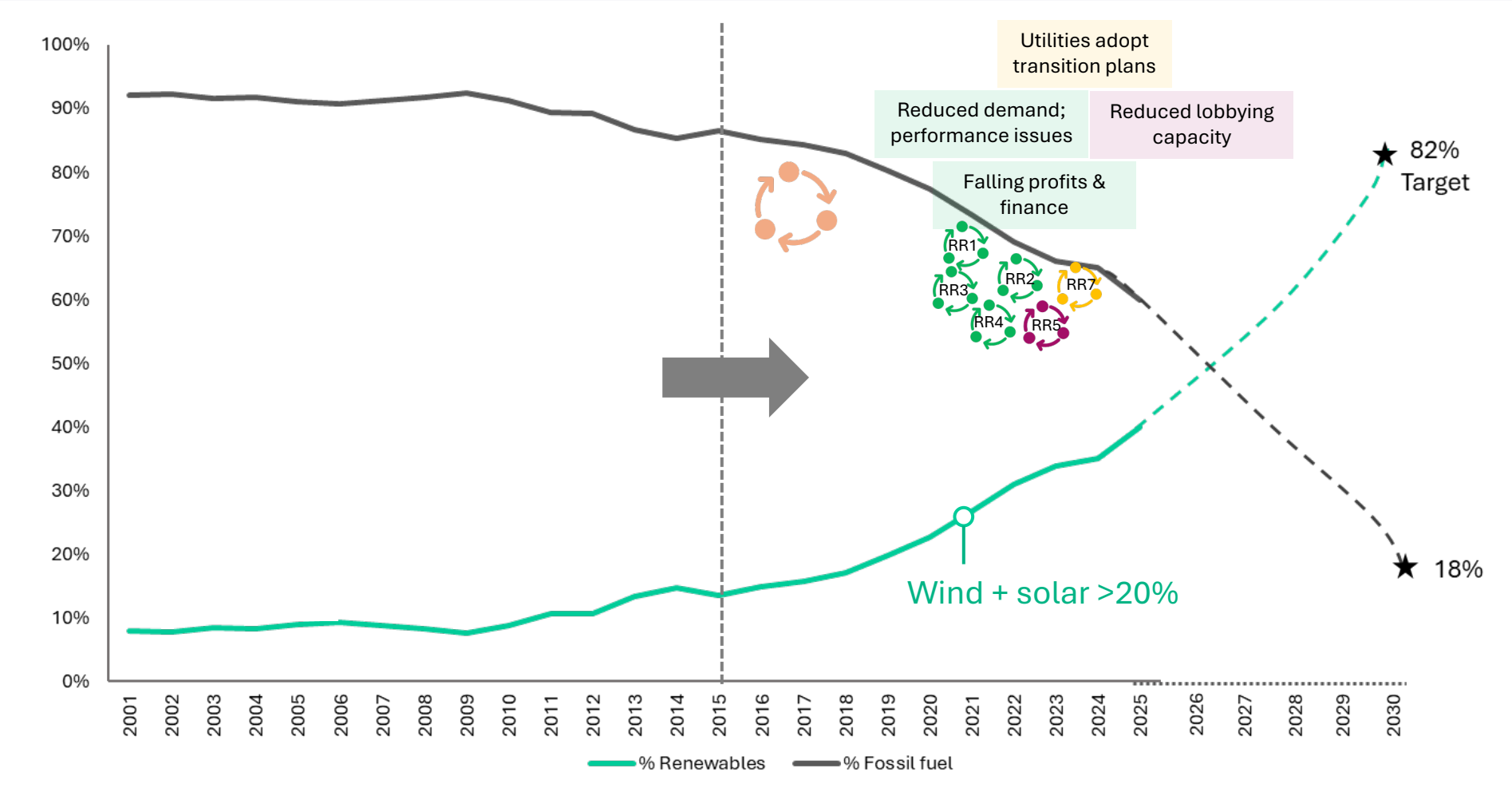
Policy

Social Actors



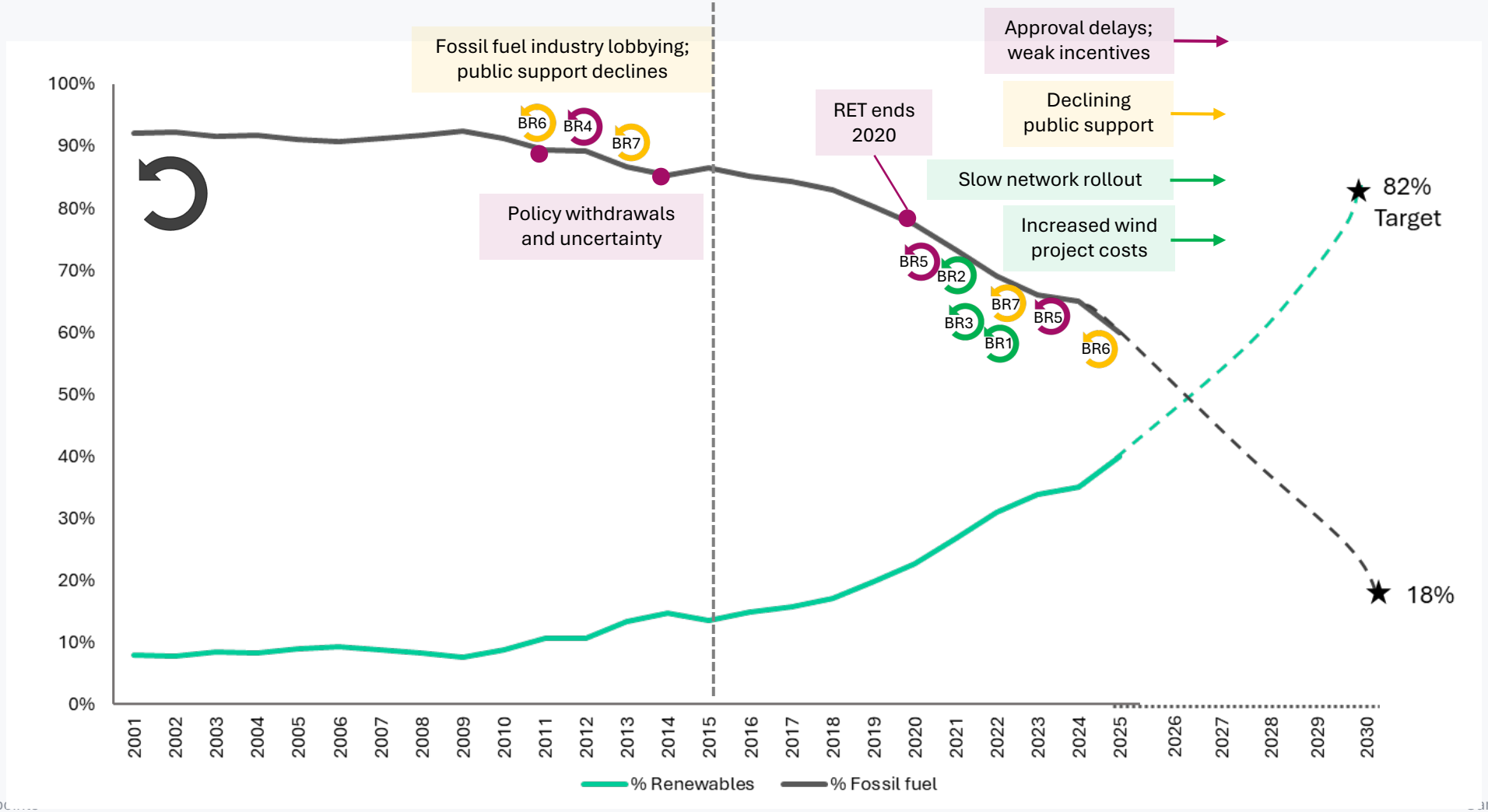
Whole-system transformation – reinforcing regime decline

- As renewables accelerated, **new reinforcing feedbacks activated** on the 'flip side' of the transition
- Emerged once solar/wind reached **market share ~20%**



Whole-system transformation – decelerating niches

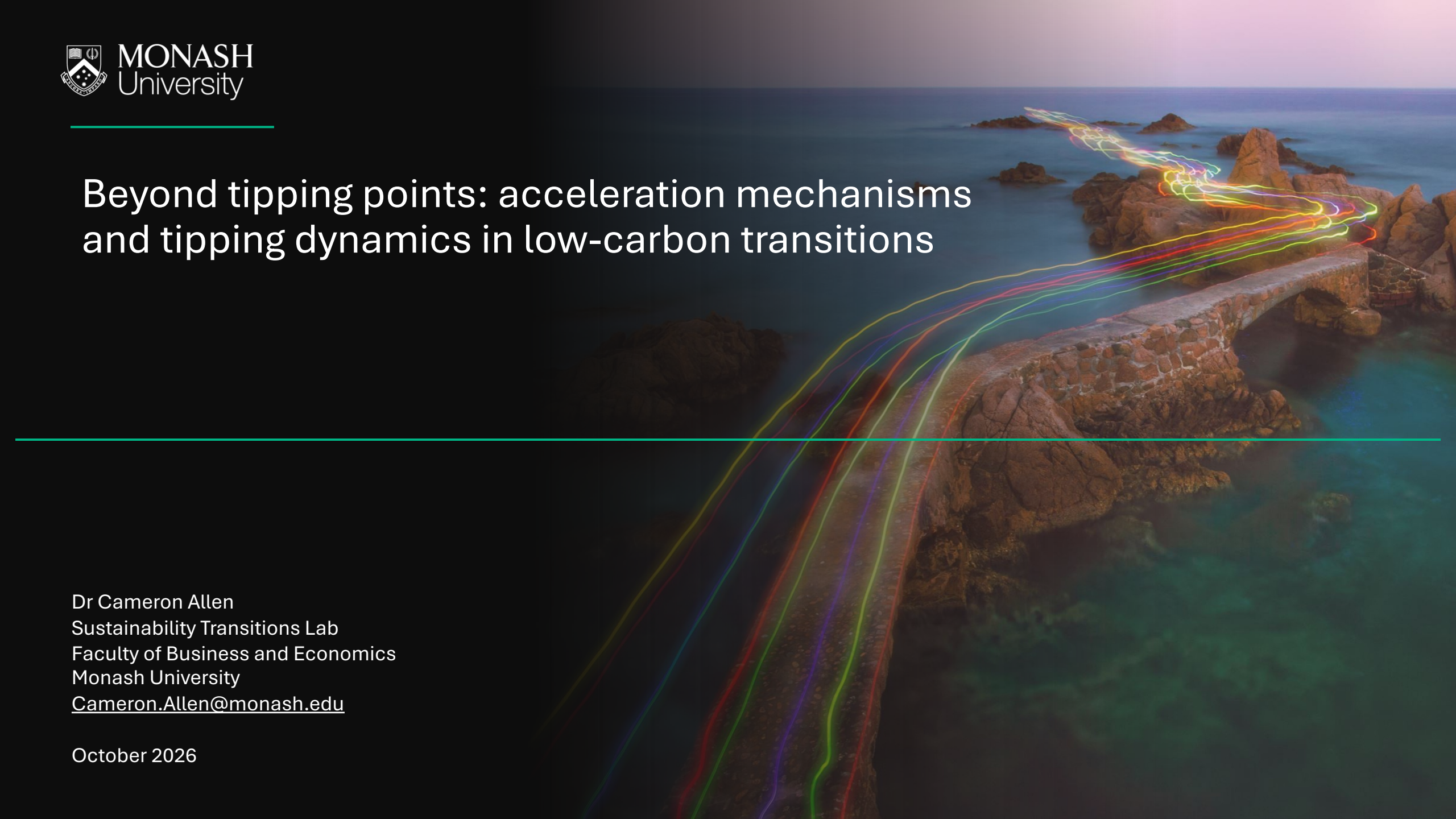
- Early political resistance and policy uncertainty; weakened after 2015
- Acceleration has resulted in new constraints – technical, infrastructure, institutional bottlenecks + social backlash and resistance



What does the Australian case tell us about socio-economic tipping points?

- ✓ **Tipping dynamics rather than single tipping points**: tipping visible in diffusion of technical components, but system transformation emerges through alignment of technologies, markets, policies and social actors.
- ✓ **Policies + cumulative feedback effects have shaped transition speed**: early public and policy support (stable targets, subsidies) catalysed early adoption and activated reinforcing feedbacks (scale, experience, learning, supportive constituencies, etc.) that drove momentum
- ✓ **Acceleration involves both niche growth and regime decline**: As renewables expanded, new reinforcing feedbacks contributed to fossil-fuel regime destabilisation, further supporting the transition (triggered at ~20%)
- ✓ **Acceleration is neither smooth nor inevitable**: Balancing feedbacks persist and evolve, with early political resistance increasingly accompanied by infrastructure/institutional bottlenecks + social backlash/justice issues during acceleration.
- ✓ **The durability of acceleration depends on addressing emerging constraints/negative feedbacks:** shift from supporting early adoption to scaling deployment, system integration, addressing bottlenecks, managing phase-out and backlash etc.
- ✓ **Build and sustain social legitimacy:** public support as a leading indicator of policy change for or against the transition; needs to be built early and sustained; fair distribution of costs and benefits as part of transition planning and design

Beyond tipping points: acceleration mechanisms and tipping dynamics in low-carbon transitions



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New study – how acceleration propagates across systems

- **Electricity is leading system in Australia** – but net-zero requires that it broaden into end-use sectors (heating, housing, mobility, etc.)
- **Acceleration can propagate across systems**, but it's a conditional and cumulative process **not an automatic tipping cascade**.
- **It depends on the maturity, configuration and readiness of connected systems**, and on whether supportive technologies, institutions and actors are sufficiently aligned.
- **For example**, Australia's renewable electricity transition has helped accelerate **residential heating electrification**, building on widespread rooftop solar adoption, mature heat-pump technologies (heating and hot water) and established supply chains.
- **However, this momentum has not translated into acceleration in housing transformation (retrofits, high performance)**, where long-lived building stocks, institutional barriers, financing and fragmented retrofit delivery remain major constraints.
- **We identify** 4 conditions for cross-system broadening that are particularly important: **(1)** compatible technologies and infrastructure; **(2)** aligned policies and institutions; **(3)** capable actors, supply chains and delivery systems; and **(4)** adopters have resources and ability needed to participate (access to capital, dwelling ownership, etc.).
- **Importantly, broadening can also generate new feedbacks and constraints – e.g.** appliance electrification has considerably outpaced building upgrades, increasing electricity demand, network and infrastructure pressures, and costs -> which can slow the electricity and heating transitions

- **From a policy perspective - sustaining acceleration** therefore requires differentiated but coordinated policies within and across systems at different stages of transition
- **And different systems can require fundamentally different policy interventions at the same time** because they occupy different transition phases.
- **Electricity**: Moving from renewable niche support towards infrastructure integration, flexibility and managed coal phase-out.
- **Heating**: Moving from technological feasibility towards widespread electrification and displacement of the incumbent gas regime.
- **Housing**: Still requiring stronger market formation, institutional development and delivery capability to accelerate high-performance construction and retrofit.

- This **challenges the idea that a tipping point in one leading system will automatically produce corresponding transitions elsewhere – or tipping cascades**. Such effects may occur but are conditional
- It also suggests that the **governance challenge is not simply to accelerate the leading system**, but also to **address the conditions preventing connected systems from responding**.

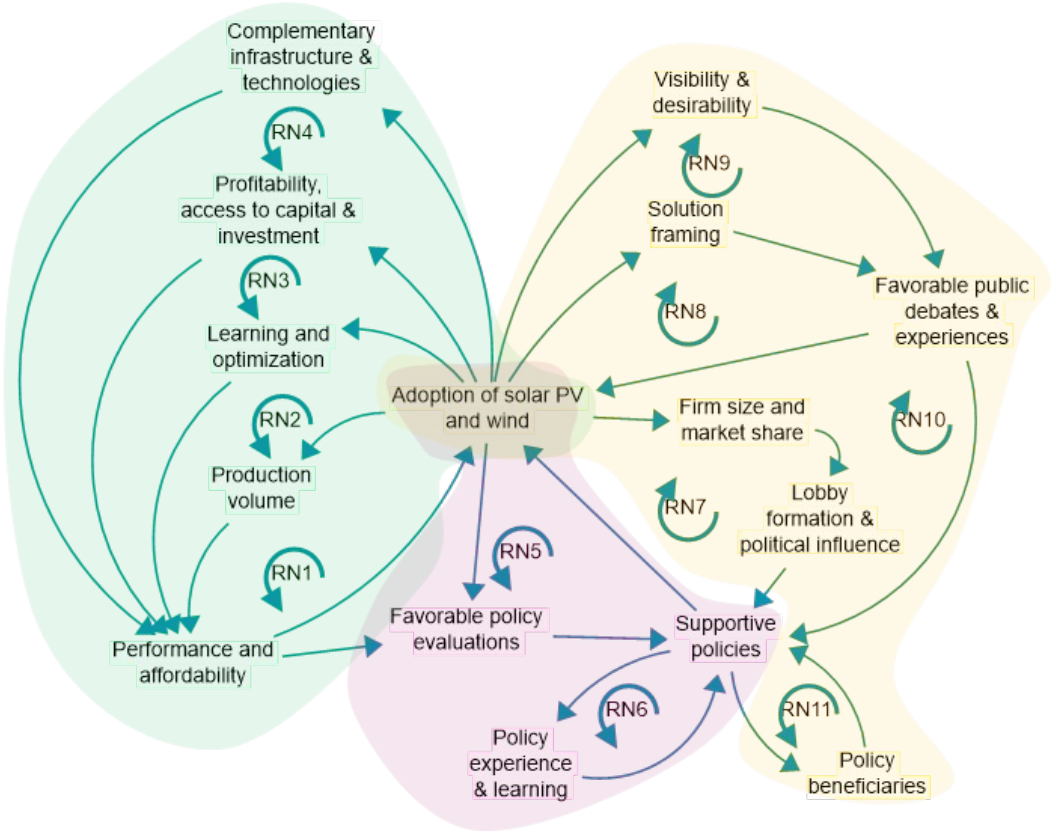
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Five policy implications for accelerating transitions

1. **Catalyse reinforcing feedbacks:** Use targeted, well-timed policies to stimulate adoption, learning, investment and supportive coalitions.
2. **Manage both growth and decline:** Coordinate low-carbon innovation and deployment with the phase-out of incumbent regimes.
3. **Adapt policies as transitions evolve:** Anticipate and address emerging technological, infrastructural, institutional and social constraints.
4. **Enable acceleration within and across systems:** Align technologies, infrastructure, policies and delivery capabilities across interconnected transitions.
5. **Build and sustain social legitimacy:** Strengthen public support, participation and equitable sharing of transition costs and benefits.

1. Reinforcing feedbacks of niche acceleration

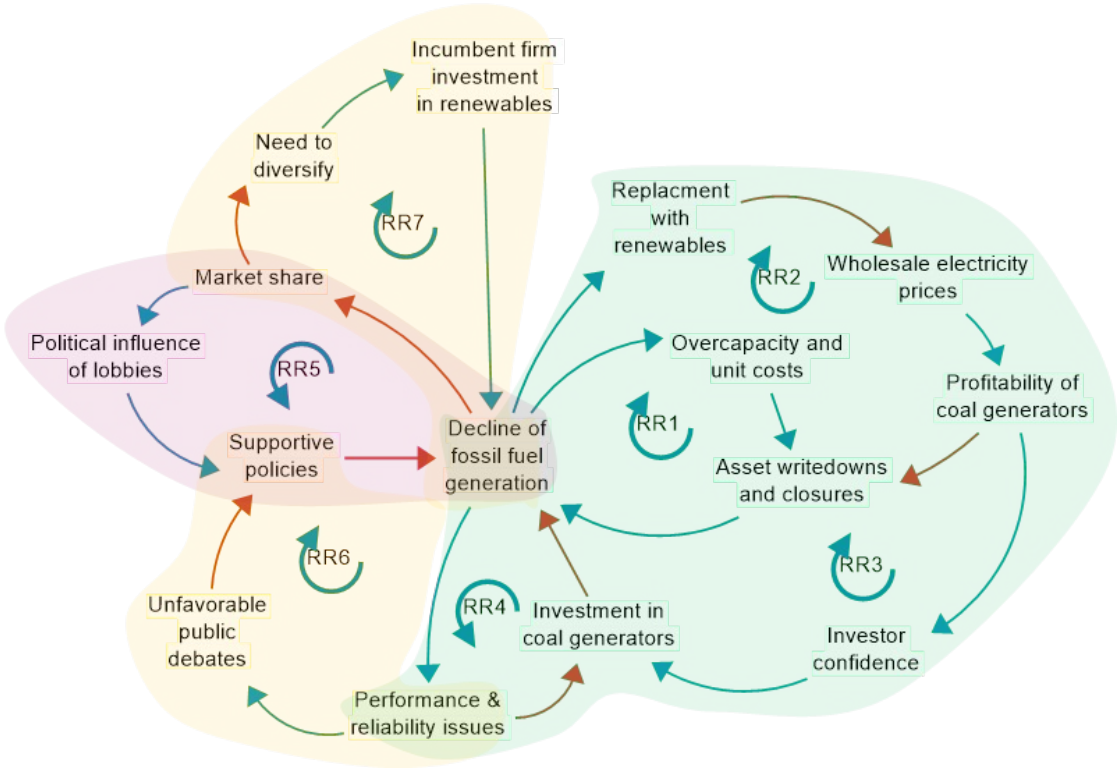
Techno-economic elements | Policy and Governance | Social Actors and Actions



Feedback and Dimension	Description
Techno-economic	
RN1 Economies of scale	As demand for solar PV and wind increased and production scaled globally, unit costs decreased which further increased demand
RN2 Learning by doing	Greater use of solar PV and wind led to enhanced learning and technological improvement, resulting in better performance and increased attractiveness
RN3 Access to finance	Growing adoption, revenues, and profitability of wind and solar PV firms enhanced investor confidence, lowering the cost of capital and stimulating further investment
RN4 Technological reinforcement	Increased deployment of solar PV and wind stimulated the development of complementary technologies (smart meters, batteries, network augmentation etc.), which in turn reinforced further adoption
Policy and governance	
RN5 Policy learning	Through experiential learning and feedback, policymakers have improved policy instruments, increasing the effectiveness of support measures
RN6 Policy support	Early successes and cost reductions fostered positive policy assessments, driving higher policy ambition and stronger policy support
Social actors and actions	
RN7 Political influence (niche)	The growth of renewable energy firms and industries enhanced their political influence via lobbying and coalition building for more supportive policy environments
RN8 Legitimacy and framing	Wider diffusion allowed advocates to portray solar PV and wind as responses to societal challenges, strengthening positive discourse and enhancing legitimacy
RN9. Visibility and experience	Greater adoption and positive experiences raised the visibility and desirability of rooftop solar PV and stimulated further adoption
RN10 Public debates (niche)	Positive public debates about renewable technologies and support for action on climate change placed pressure on policymakers to increase policy supports
RN11 Policy beneficiary feedbacks	Subsidies supporting rooftop solar PV created beneficiaries, fostering growing support for maintaining and strengthening such policies

2. Reinforcing feedbacks of regime decline

Techno-economic elements | Policy and Governance | Social Actors and Actions

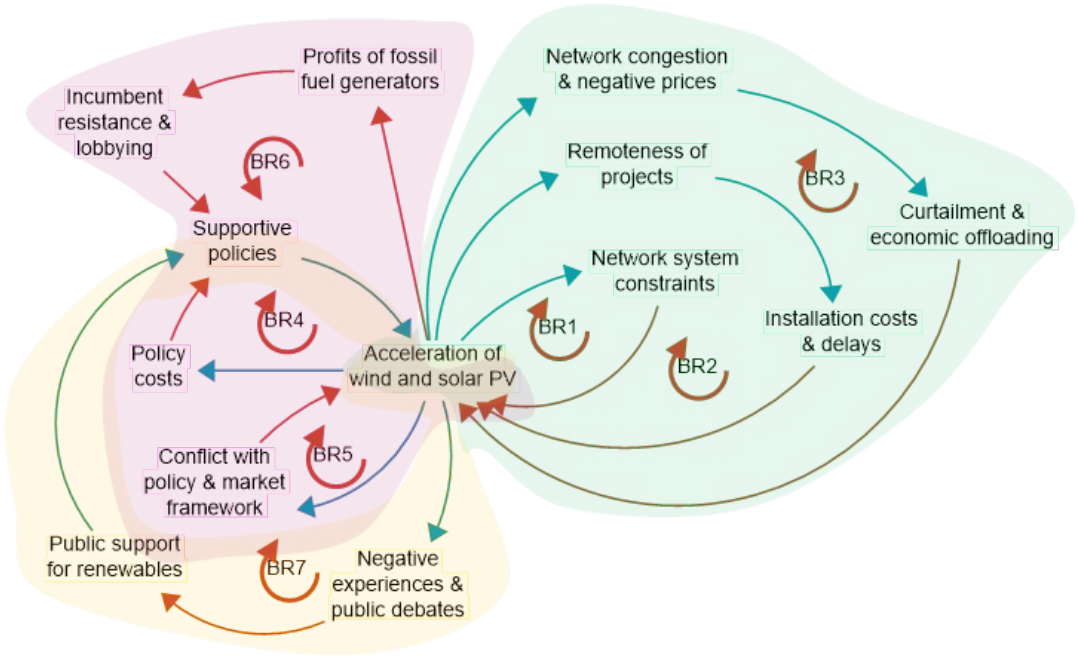


Feedback and Dimension	Description
Techno-economic	
RR1. Diseconomies of scale	Declining demand for coal-fired generation has created overcapacity, raising unit costs and prompting asset write-downs and further reducing market share
RR2. Price effects	Rising renewable generation has exerted a deflationary effect on wholesale electricity prices further decreasing the profitability of coal power plants
RR3. Profitability and investment	As profitability has deteriorated, investment and ownership in coal assets have become increasingly unattractive, reducing investment
RR4. Performance issues	Declining returns and shorter payback windows have prompted operators to defer maintenance and reinvestment in ageing infrastructure which reduces reliability and performance, further impacting investment
Policy and governance	
RR5. Lobbying capacity (regime)	The market share of major utilities has declined which reduces their market power and ability to influence political debates and supportive policies
Social actors and actions	
RR6. Public debates (regime)	Increasing concerns regarding the misalignment of coal with the need to address climate change has resulted in both rising public support for renewables and phase out of coal power
RR7. Incumbents pivot to niche	The incumbent electricity generation industry is diversifying away from fossil fuels towards renewable

Techno-economic elements

Policy and Governance

Social Actors and Actions



Feedback and Dimension	Description
Techno-economic	
BR1. Infrastructure lock-in	Australia's centralised electricity system and grid network were designed for large, baseload generation which has created systemic barriers to renewable integration resulting in delays, costs and slow rollout
BR2. Supply constraints and higher costs	Supply chain bottlenecks and escalating project costs have further slowed large-scale renewables, particularly wind
BR3. Limits to success (curtailment)	Growing market penetration of renewables has introduced price volatility and reliability concerns, leading to curtailment and reducing revenues and investment
Policy and governance	
BR4. Escalating policy costs	Rapid adoption of rooftop solar led to increasing costs associated with generous feed-in tariffs which were subsequently wound back
BR5. Policy lock-in	Policy discontinuity and regulatory misalignment have discouraged or delayed investment and constrained renewables
Social actors and actions	
BR6. Incumbent resistance	Lobbying and campaigns by incumbents has led to policy uncertainty and fractious public debates that have slowed the growth of renewables. Regulatory gaming of electricity markets and other strategies by incumbents to stifle renewables have also been common
BR7. Social backlash	Concerns about energy prices and negative impacts of renewables have led to local opposition and reduced public support for the transition.