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Modelling energy transitions pathways using insights from the sustanable transitions literature

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Flexible Nordic Energy Systems

DTU

Modelling energy transitions pathways

Using insights from the literature on sustainability transitions

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Nordic Energy Research

Background - energy modelling

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- Must enable quantitative description of energy transition, not only in the technology domain, but also in the institutional, market, and social domains
- Must account for endogenous factors that drive transition processes, not just external impacts on the system

Strengths and limitations of 'traditional' energy models:

- Focus on technological and economic factors - high technological detail (performance, costs); models interactions between energy sub-systems; geographical coverage
- Neglect market failures and adjustment delays;
- Ignore social, political and behavioural factors or at best treat them as exogenous to the system

Background - flexibility analysis

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- Flexibility a precondition for achieving low-carbon energy systems with high shares of variable renewable energy (VRE) sources
- It is a transition issue in the medium to long term
  - Demand side - e.g. peak shaving, flexible heating & cooling, …
  - Energy conversion and storage - e.g. power-to-gas, power-to-heat, battery storage, reserve generation capacity
  - There are technological, economic, behavioural, institutional (including regulatory) barriers to increasing flexibility in energy systems
- **Flex4res project** on Nordic energy system - costs and potentials, technological and regulatory barriers, coupled energy markets, market design, energy system model, transitions pathways, …
- Modelling of energy transitions pathways should consider flexibility measures as enabling factors for integration of high shares of VRE

Aims of the paper

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- Discuss how modelling of energy scenarios as sustainable energy transition pathways can be improved by integrating insights (factors, mechanisms, linkages, etc.) drawn from the sustainable transitions (ST) literature

- Discuss alternative energy modelling approaches in view of their ability to consider ST factors. Focus is on system dynamics modelling (SDM) vs. 'traditional' optimisation models.

- Propose how SDMs can be applied to the case of flexibility in an energy system with high shares of variable renewable energy

- Assess the ST concepts in terms of their use in SDM and relevance for analysis of flexibility in energy systems

Three co-evolving systems influence energy transitions

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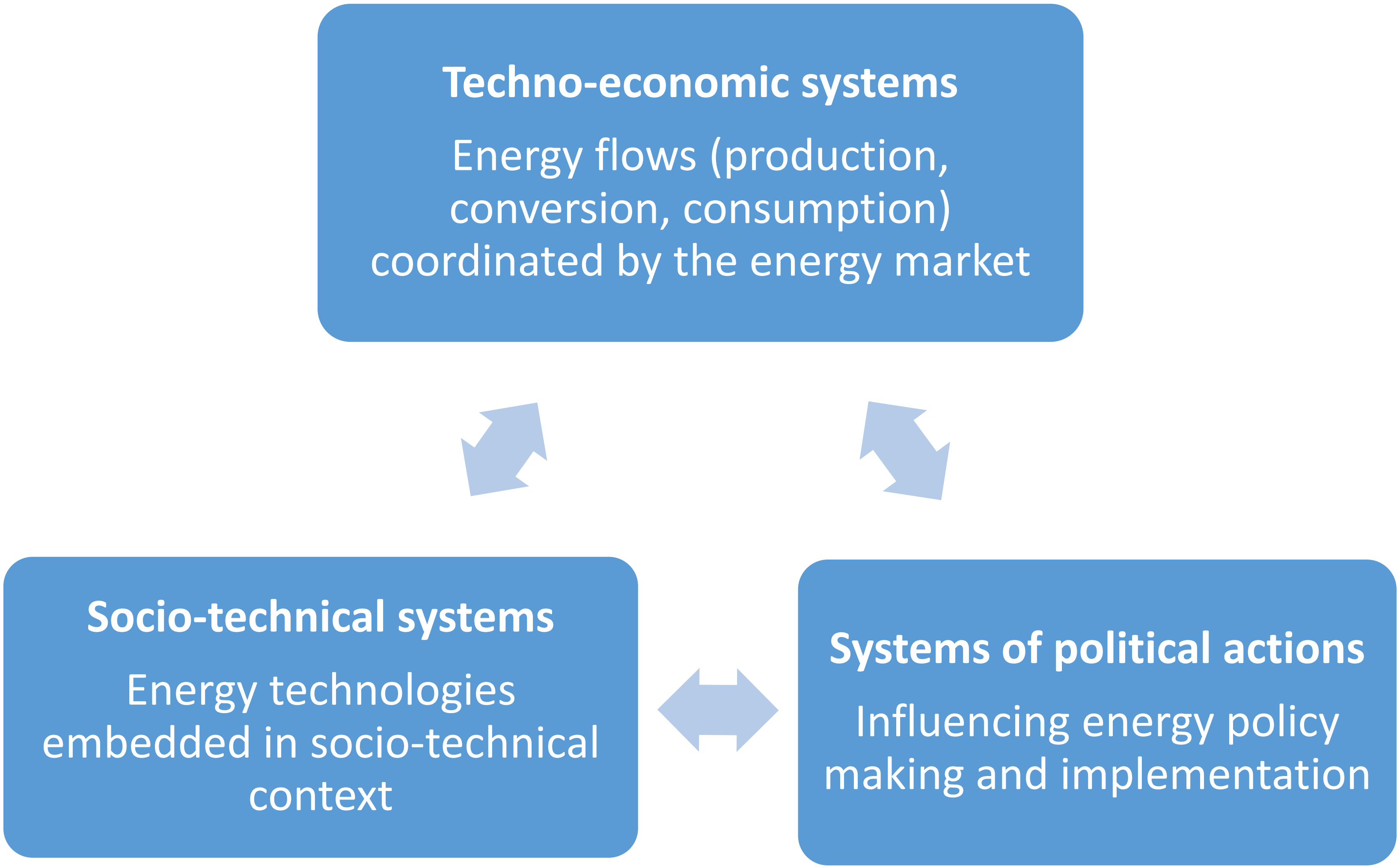

Theoretical perspectives for analysing the systems

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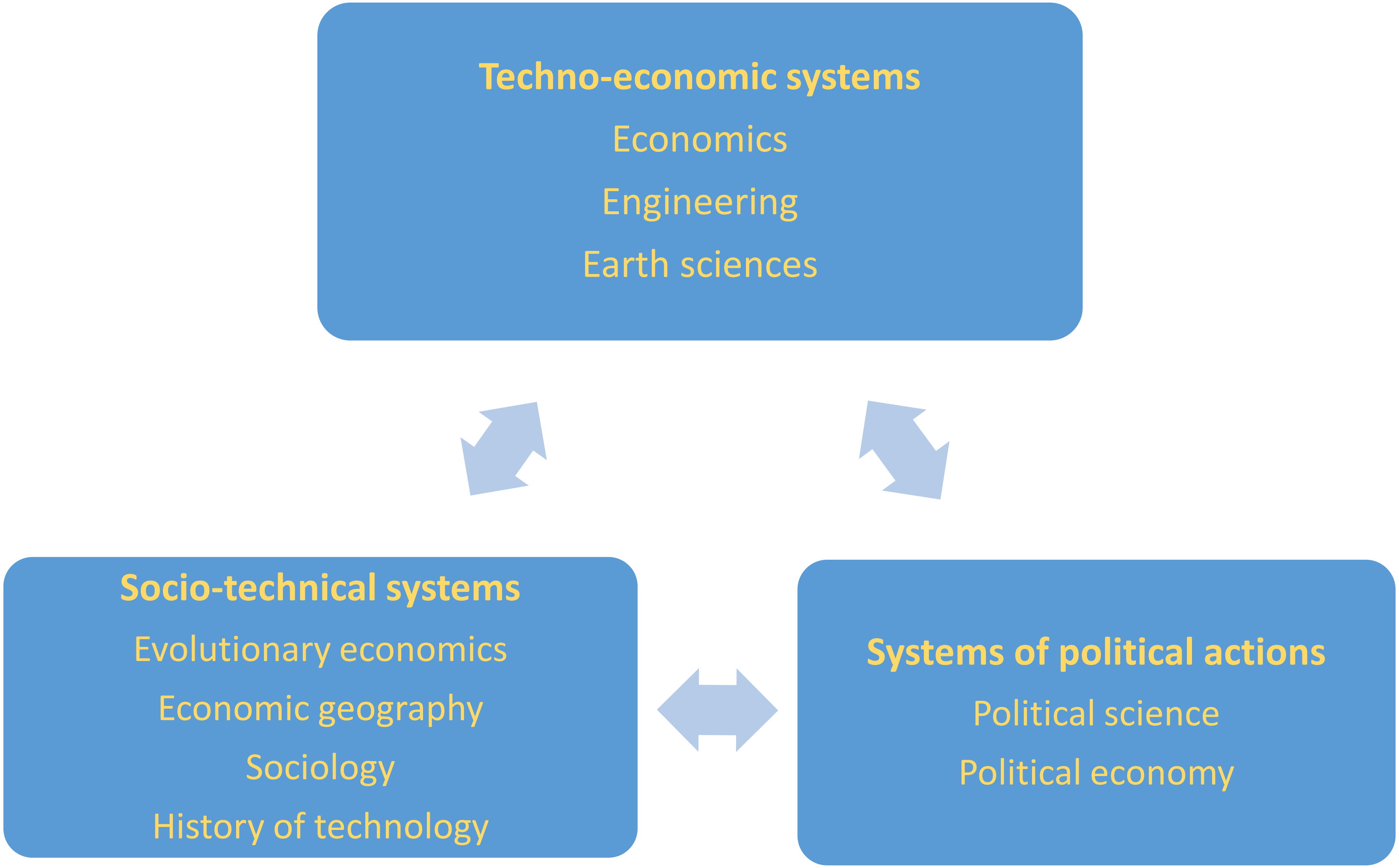

ST concepts for improved modelling of energy transition pathways

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ST concept	Description	Sources
Transitions pathways	Patterns of changes in socio-technical systems … that lead to new ways of achieving specific societal functions. TPs involve … reconfigurations across technologies, supporting infrastructures, business models and production systems, as well as the preferences and behavior of consumers.	Turnheim et al
Typology of transitions pathways	• Transformation pathway • Reconfiguration pathway • Technological substitution pathway • De-alignment and re-alignment pathway	Geels & Schot
Strategic niche management	The creation, development and phase-out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of learning about the new technology and enhancing its further development and use	Kemp et al
Expectations and visions	The role of promises and expectations in technological development – how promises about technologies are converted into design specifications. Expectations only contribute to new technology niches if they become a part of agenda building processes	Hetland; Lente and Rip; Geels and Schot
Path dependence	Path dependence is the tendency of institutions or technologies to become committed to develop in certain ways because of their structural properties or their beliefs and values	Br Encycl
	Path dependence .. suggests the existence of 'lock in' mechanisms that can cause some technologies, behaviors or policies to persist or dominate even if "superior" alternatives	Klitkou et al

ST concept	Description	Sources
Lock in mechanisms	Positive feedbacks or increasing returns to the adoption of a selected technology. As a result, incumbent technologies have a distinct advantage over new entrants. Mechanisms that reinforce a certain pathway of economic, technological, industrial and institutional development	Arthur 1994 Klitkou et al 2015
	• Learning effects and learning processes - e.g. decreasing costs of renewables, learning-by-using, learning in niches, etc. • Institutional learning effects - formal institutions favour certain policies • Increasing returns to scale - fixed costs • Increasing returns to scope - advantages through product variety • Informational increasing returns - tech diffusion • Network externalities - standard setting in technological domains • Technological interrelatedness and infrastructure	Klitkou et al 2015; various sources
Institutions and actors	• Political processes at local, national and international levels • Strategic actions of core industry actors, regarding technology, markets and regulation • Consumer behaviour and perceptions	Holtz et al Geels et al Nygaard & Bolwig

System dynamics models of energy systems

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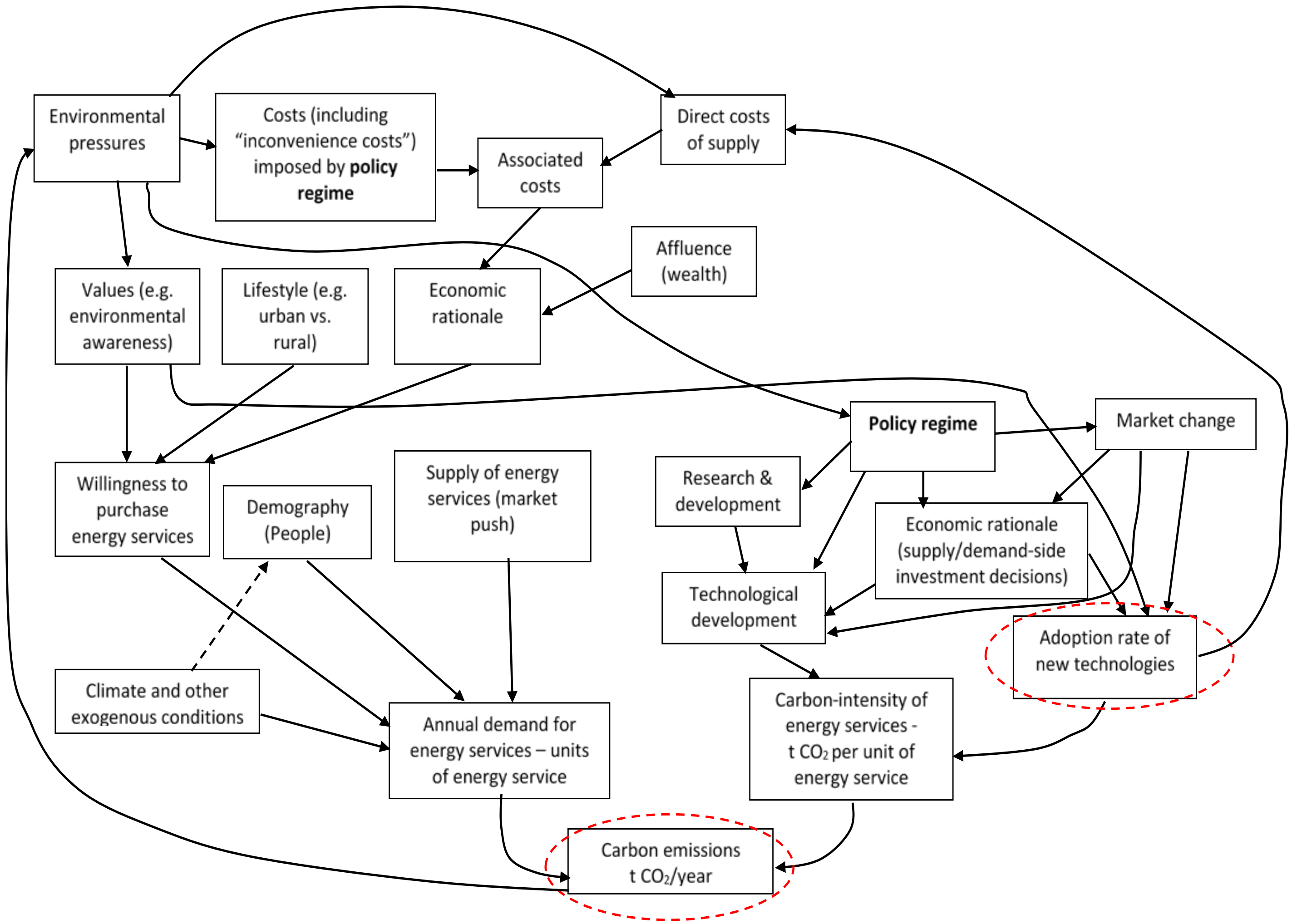
- SDMs capture co-evolution of systems - techno-economic, socio-technical and political - and so give a more realistic representation of energy system dynamics:
- Information feedback loops affecting demand and investment decisions, regulations and policy implications, environmental awareness of society;
- Delays in material (e.g. power generation capacity) and informational (e.g. knowledge about new technologies) factors;
- Co-development and mutual interaction of material (e.g. capacities of technologies) and non-material (e.g. level of expertise) stocks;
- Non-linear causal relations governed by reinforcing and balancing forces (e.g. diffusion of new technologies, limits to growth) which are characteristic for technology disruptions in socio-technical systems.

Elements of systems dynamics model representing 'socio-technical' energy transition



Conceptual model of nonlinear energy transition

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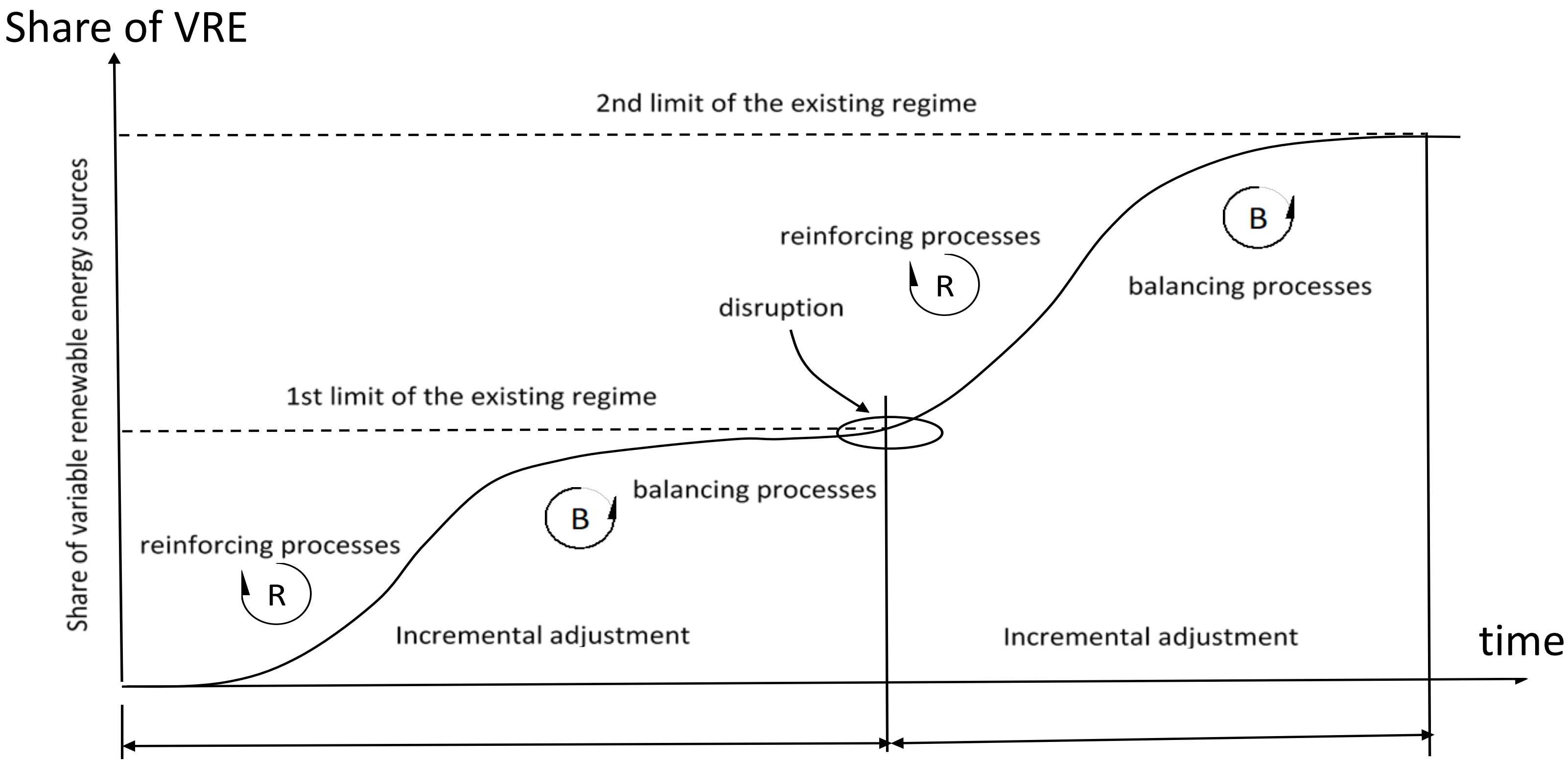

Fig 2. Dynamics of share of variable renewable energy sources as portrayed by interaction of reinforcing and balancing processes and disruption

Interaction between flexibility solutions and adoption rate of RES

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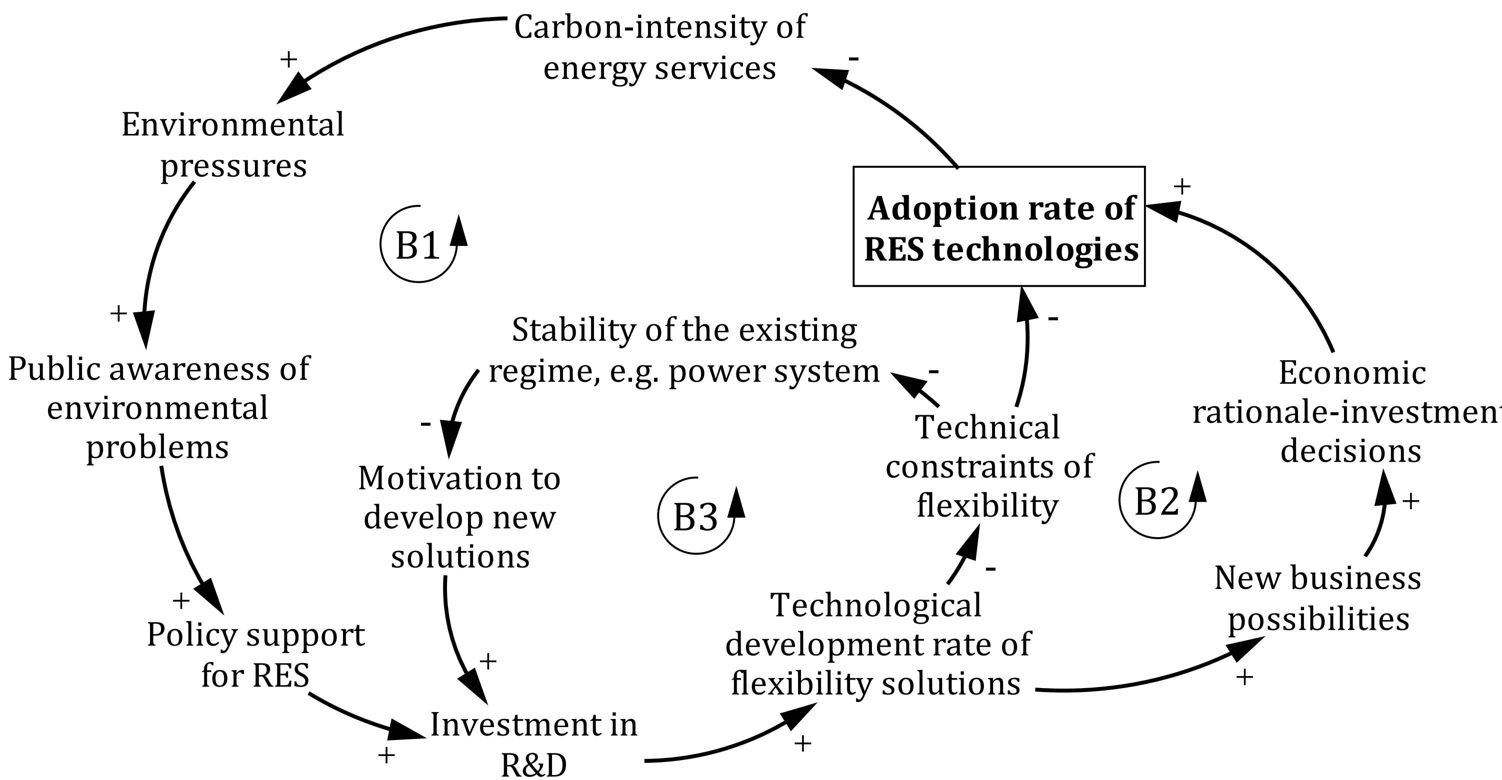

Causal loop diagram illustrating balancing effects caused by changes in the adoption rate of renewable energy source (RES) technologies

Integration of ST concepts in SDM and relevance for analysis of flexibility

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ST concept (examples)	Approach in system dynamics models	Relevance for analysis of flexibility
Reconfigur-ation pathway	Development of novel technologies and their incorporation into existing system represented by co-evolving S&F. The novel technological solutions gradually overtake existing solutions when a certain maturity is reached.	Digitalization, development of demand-side response technologies and solutions, incl. new linkages between established utilities and ICT companies in smart grid development, smart meter apps etc.
Strategic niche management	Driver of technological and institutional disruption (e.g. balancing loop B3, Fi. 5). Development of complementary technologies and infrastructures, supporting technology diffusion portrayed as co-flows.	Industrial development that provides flexibility solutions. Development of efficient electric heating in residential and service sector and in district heating systems (power-to-heat flexibility)

ST concept (examples)	Approach in system dynamics models	Relevance for analysis of flexibility
Strategic actions of core industry actors	Activities of core industry actors which hamper development of new technologies create “inconvenience costs” for new technologies. Activities which lead to faster development and diffusion of new technologies may be modelled similarly to learning effects.	Investments in flexibility enabling technologies, such as electric vehicles, battery storage. Decisions of large utilities to engage in flexibility services. Industry lobbying of energy policies.
Political entities and processes	Political processes can be considered by creating feedbacks from stocks which measure important societal factors, e.g. annual CO_2 emissions to certain political leverage points, e.g. support for RES (e.g. balancing loop B1 in Fig. 5).	New market mechanisms and national regulation. Political support to tax reforms to promote a flexible energy system, e.g. electrification of heating and transport. Capacity of state agencies to implement policies.

Concluding observations

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- Concepts from the ST literature can help identify important factors to consider in energy models of energy transitions pathways
- Many of ST concepts are relevant to analysis of energy flexibility
- SDMs can capture the co-evolution of techno-economic, socio-technical and political factors - they can be integrated in SDMs as reinforcing and balancing loops …
- Energy optimisation models are superior to SDMs regarding technological detail, coverage of connected sub-systems (heat, electricity, …), geographical scope…
- A way forward - combine SDMs with energy optimisation models - possibly through soft coupling
- … possibly achieving more realistic representations of energy scenarios as transition pathways including issues related to flexibility

Thank you for listening

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