How People Respond to Policies: Integrating Behavioural and Decision-Making Theories into Systems Thinking for Sustainability Transformations

Christoph Schünemann

Leibniz Institute of Ecological Urban and Regional Development
Weberplatz 1, 01217 Dresden, Germany

Contact: c.schuenemann@ioer.de; ORCID: orcid.org/0000-0002-1214-8593

Abstract

Understanding how individuals, groups and societies respond to transformative policies is essential for designing effective sustainability policies and coordinated policy mixes. While psychology, behavioural economics and the social sciences provide a rich body of theories explaining human decision-making and behavioural change, these perspectives remain fragmented and are rarely translated into systems models. At the same time, the social component of socio-technical (STS), socio-ecological (SES) and socio-ecological-technological (SETS) systems is often represented only through highly aggregated concepts such as awareness, acceptance or behaviour, limiting the ability of models to realistically capture societal responses to interventions.

This article addresses this gap by examining how behavioural knowledge can inform Systems Thinking models for sustainability policy design. It first reviews major decision-making and behavioural theories before comparing two complementary qualitative modelling strategies: (i) systemic decision-making models that place behavioural processes at the centre of the analysis, and (ii) STS, SES and SETS models that embed behavioural processes within broader sustainability systems. It then discusses how both approaches can, where appropriate, be translated into quantitative System Dynamics simulations for analysing temporal dynamics and policy scenarios. The paper argues that the challenge is not simply to integrate complete behavioural theories into systems models, but to identify and represent the behavioural mechanisms most relevant to the modelling purpose. Overall, it provides a structured perspective on representing behavioural mechanisms in Systems Thinking models and outlines future directions for strengthening the representation of the social component in complex sustainability systems.

Keywords: behavioural public policy modelling, decision-making theories, behavioural theories, policy assessment, policy target group

1 Introduction

The design of effective policies and coordinated policy mixes to enable sustainability transformation increasingly hinges on a realistic representation of how individuals, groups and society respond to those interventions (Haddad et al., 2022; Raven & Walrave, 2020). While traditional policy analysis has often treated policy target groups as decision-makers as rational, fully informed actors, a growing body of research in environmental psychology, behavioural economics, political science and the broader social sciences demonstrates that human behaviour is non-linear, bounded by cognition, social norms and institutional contexts (Kern et al., 2019; Lane & Rouwette, 2023; Rogge & Reichardt, 2016; Schrieks et al., 2021). Consequently, the emerging field of *behavioural public policy modelling* seeks to embed decision-making and behavioural-change processes within ex-ante policy assessments so that the intended effects of policies or coordinated policy mixes can be evaluated not only for their technical or ecological effectiveness but also for their likelihood of being adopted by target groups without causing unintended side effects (Kaufman et al., 2021; Strassheim, 2021).

Over recent decades, research from psychology (e.g. Ajzen, 1991; Bandura & Walters, 1977), behavioural economics (e.g. Kahneman & Tversky, 1979; Thaler, 2018), and social sciences (sociology) (e.g. Macy & Willer, 2002; Rogers, 2003) has provided a diverse set of theories and frameworks to explain how individuals and groups make decisions and alter behaviour. While decision-making theories focus on how choices are made, behavioural theories explain why people act in specific ways, and behavioural change theories address how actions evolve over time. Integrating these perspectives is essential to assess whether policies achieve their intended impacts on target groups. Despite the richness of these individual approaches, the field remains fragmented, with limited guidance on how to combine insights from multiple traditions into holistic policy assessment frameworks (Schlüter et al., 2017).

Despite these advances, considerably less attention has been paid to how behavioural knowledge should be represented in systems models used to analyse sustainability transformations and support policy assessment and design. Broadly speaking, two complementary modelling strategies can be distinguished. One approach places human decision-making itself at the centre of the analysis, resulting in systemic decision-making models that explicitly represent behavioural processes and their interactions through qualitative systems mapping. A second approach embeds human behaviour within broader socio-technical (STS), socio-ecological (SES) or socio-ecological-technological (SETS) systems models, where social processes interact with ecological and technical subsystems to explain the dynamics of complex sustainability systems.

While these broader systems frameworks have become increasingly influential in sustainability research, the representation of the social component often remains considerably less developed than the ecological and technical components (Müller-Hansen et al., 2017). Social systems are frequently represented through highly aggregated concepts such as awareness, acceptance or behaviour, limiting the ability of systems models to realistically capture how actors respond to transformative policies and interventions (Schlüter et al., 2017). Conversely, systemic decision-making models provide much richer representations of behavioural processes but typically focus on specific actor groups rather than the wider socio-ecological-technical system. This raises a fundamental methodological question:

***How detailed should the representation of human decision-making be for different types of systems models* or *how much social complexity belongs into which type of systems model*?**

Existing behavioural theories explain isolated aspects of human decision-making, yet sustainability policies operate within highly interconnected systems characterised by feedback processes, adaptation and nonlinear dynamics. Rather than viewing behavioural theories as competing explanations, Systems Thinking provides a framework for understanding how their underlying mechanisms interact within complex systems. It explicitly represents feedback structures and interdependencies, irrespective of whether the resulting models remain qualitative or are subsequently translated into quantitative simulation models.

This paper contributes to bridging this gap by providing a structured overview of existing theories and concepts to model decision-making and behavioural change in policy contexts. It first situates the origins of these theories, comparing perspectives from psychology, behavioural economics, and social sciences, and highlighting their complementary strengths and limitations in understanding individual and collective behaviour. It then examines two complementary qualitative modelling strategies: (i) systemic decision-making models that place behavioural processes at the centre of the analysis, and (ii) the integration of behavioural components into broader socio-technical (STS), socio-ecological (SES) and socio-ecological-technological (SETS) systems models. Finally, the paper discusses how both qualitative modelling approaches can, where appropriate, be translated into quantitative System Dynamics simulation models to analyse temporal dynamics and evaluate alternative policy scenarios.

By systematically linking established decision-making and behavioural theories to the representation of behavioural mechanisms in complex system models, this paper provides researchers and policymakers with a framework to better anticipate behavioural responses, identify feedback mechanisms and improve the design and assessment of transformative sustainability policies.

2 Existing theories and concepts to model decision-making or behavioural change processes for policy addressees

2.1 Behavioural policy modelling

Modelling human behaviour in public policy is a relatively new and evolving field, shaped by ongoing research in environmental psychology, behavioural economics, political science and social science (Schrieks et al., 2021). Central questions include: whose behaviour should be modelled, and for what purpose should it be changed? To assess the ex-ante effectiveness of future transformative policy or policy mixes, it is essential not only to understand the complex dynamics they may trigger, but also to determine whether it will actually alter the decision-making or behaviour of the policy target groups in the intended way. Besides assessment by expert feedbacks, this can be addressed through behavioural modelling in policy assessment, which mainly uses decision rules to represent behavioural mechanisms at the individual or group level (Schrieks et al., 2021). The goal is to model decision-making and behavioural change processes which are inherently complex and non-linear. Approaches range from simple ad hoc assumptions and psychological theories to methods like machine learning and artificial neural networks (Lane & Rouwette, 2023), which provide comprehensive syntheses for integrating human decision-making into complex system models. A key challenge lies in balancing model complexity with parameterizable: rules must reflect real-world decision-making without becoming too intricate for empirical calibration via surveys, expert judgment, or data science.

2.2 Decision-making and behavioural theories for policy modelling

The scientific landscape regarding decision-making and behavioural change draws on three distinct academic traditions, each with its own analytical focus, level of abstraction, and methodological orientation, as summarised in Table 1. Psychology and behavioural science operate primarily at the individual level, offering detailed, granular insight into cognitive and motivational processes through conceptual and qualitative frameworks such as the Theory of Planned Behaviour (Ajzen, 1991), the COM-B Model (Michie et al., 2011), and Habit Theory (Verplanken & Orbell, 2003). While rich in explanatory depth, these models are often limited in their generalisability across broader populations or societal contexts. Behavioural economics, by contrast, spans the individual to the societal level and is characterised by more formalised, quantitative models, based on Nudge Theory (Thaler, 2018), Prospect Theory (Kahneman & Tversky, 1979) and Bounded Rationality (Simon, 2000), that are frequently calibrated to empirical data (Schlüter et al., 2017). However, this precision comes at the cost of simplifying assumptions about human preferences and decision processes (Dold et al., 2025). Finally, sociology and social science situate behaviour within group and societal dynamics, using explanatory frameworks such as Diffusion of Innovations (Rogers, 2003), Social Practice Theory (Reckwitz, 2002), and Collective Action Theory (Heckelman, 2019) to account for social norms, networks, and collective patterns of behaviour. These approaches offer strong conceptual and explanatory power at scale, though they are less suited to generating precise, individual-level predictions. Together, these three traditions provide complementary lenses through which decision-making processes and behavioural change can be understood, from the cognitive processes of individuals to the social norms and values shaping societies.

Table 1: Academic backgrounds on modelling decision-making and behaviour

	Psychology / Behavioural science	**Behavioural economics**	**Sociology / Social science**
Aim	Psychological models provide detailed, granular insights into individual behaviour, capturing cognitive and motivational processes, but are often limited in scope and generalizability	Behavioural economics provides broad, quantitative insights into policy responses, but relies on simplifying assumptions about decision-making and preferences.	Sociological approaches focus on conceptualizing societal-level phenomena, such as norms, networks, and collective practices, offering explanatory power for group behaviour rather than precise individual-level predictions
Behavioural level	Individual, group to societal	Individual, group to societal	Group to societal
Exemplarily theories	- Theory of Planned Behaviour - COM-B Model - Habit Theory	- Nudge Theory - Prospect Theory - Bounded Rationality	- Diffusion of Innovations - Social Practice Theory - Collective Action Theory
Degree of formalisation	Primary explanatory, conceptual, qualitative or semi-quantitative models	Primarily quantitative, formalised models, often calibrated to data with simplifications	Primary explanatory, conceptual, qualitative or semi-quantitative models

Table 2 compares theories and concepts relevant to understanding decision-making, behaviour and behaviour change. Decision-making theories and concepts focus on describing how individuals or groups select among alternatives for a conscious decision (Kahneman & Tversky, 1979). They emphasise cognitive processes, heuristics and rationality, often in single, discrete decision situations. Behavioural theories or concepts explain why people behave in a certain way by considering factors such as attitudes, social norms, and perceived behavioural control (Ajzen, 1991). They are particularly useful for predicting short- to medium-term behaviours. Behavioural change theories or concepts focus on the processes through which behaviour evolves over time (Kaufman et al., 2021; Prochaska & Velicer, 1997). They often describe stages, motivational factors, and environmental influences that facilitate long-term adoption of desired behaviours.

For the purpose of modelling the policy impacts on the target group response, the selection of the most suitable theory or concept depends of the intent of the policy. If the policy or policy mix aims to change the long-term behaviour of a target group, then behavioural change theories and concepts are appropriate. An example might be homeowners that gradually change their behaviours (install insulation, adopt solar, use efficient appliances) through stages of awareness, preparation, action and maintenance. If the policy is focussed more short-term to change the decision-making process of its target group, then decision-making theories and concepts are suitable to use. An example might be new subsidies for energy renovation measures of buildings that aim to enhance homeowners' decisions towards performing more energy renovation measures by influencing the weighing the pros and cons. It is important to note, that it is reasonable to select not only one decision-making theory or behavioural change theory to model human response because the different theories have their specific purpose in describing decision-making and behavioural change while neglecting other elements a different theory might consider more explicitly. Accordingly, for modelling the policy impacts on the target group response, it might also be expedient to include theories from both, behavioural change and decision-making.

Table 2: Comparing decision-making, behavioural and behavioural change theories and concepts

	Decision-making theories & concepts	**Behavioural theories & concepts**	**Behavioural Change theories & concepts**
Aim of theory	Explain how individuals or groups choose between alternatives	Explain why people behave in a certain way	Explain how and why behaviour changes over time
Characteristics	- Focus on cognitive processes - Often single decision situations - Examines rationality, heuristics, biases	- Focus on behaviour determinants - Include attitudes, social norms, perceived control - Often applied in short- to medium-term prediction	- Focus on behavioural development over time - Include stages, motivation, environment, self-efficacy - Often used for intervention design
Example theories/models	- Rational Choice Theory - Bounded Rationality (Herbert Simon) - Prospect Theory (Kahneman & Tversky)	- Theory of Planned Behaviour (Ajzen) - Health Belief Model - COM-B Model	- Diffusion of Innovations (Rogers) - Social Cognitive Theory (Bandura) - Rubicon concept
Example: transformation towards climate-neutral buildings	Homeowners decide between different energy renovation measures by weighing the pros and cons	Homeowners adopt energy-saving behaviours based on attitudes toward sustainability, social influence and perceived ease	Homeowners gradually change behaviours (install insulation, adopt solar, use efficient appliances) through stages of awareness, preparation, action and maintenance

2.3 From behavioural theories to behavioural mechanisms in system models

While the theories introduced above originate from different scientific disciplines and differ in their analytical focus, explanatory purpose and level of abstraction, they all seek to explain how individuals and groups make decisions, behave and respond to external interventions. Rather than representing competing explanations, they provide complementary perspectives on human behaviour and decision-making. For systems modelling, however, complete behavioural theories are rarely transferred directly into models. Instead, they provide conceptual foundations from which relevant behavioural mechanisms can be identified and represented according to the purpose of the model.

This distinction is particularly important because decision-making theories, behavioural theories and behavioural change theories address different aspects of human behaviour. Decision-making theories primarily explain how choices are made, behavioural theories explain why people behave in particular ways, while behavioural change theories describe how behaviour evolves over time in response to interventions or changing. Rather than selecting a single theoretical perspective, systems models can combine complementary behavioural mechanisms originating from different theories to provide a more comprehensive representation of the social component of complex systems.

The central challenge is therefore not deciding which behavioural theory should be incorporated into a model, but rather which behavioural mechanisms are required to adequately represent human decision-making and behaviour for the specific modelling purpose. Table 3 illustrates this conceptual transition by showing how selected behavioural theories inform behavioural mechanisms and how these may subsequently be represented within systems models.

Table 3: From behavioural theories to behavioural mechanisms in systems models for three examples

Behavioural theory	Behavioural mechanism	Possible representation in systems models
Bounded Rationality	Individuals make decisions under limited information, limited cognitive capacity and uncertainty. Rather than optimising, they rely on heuristics, simplify complex situations and satisfice. Decision quality depends on perceived rather than objective information.	Information availability; perceived complexity; cognitive load; uncertainty; search effort; experience; heuristics; aspiration level; perceived costs and benefits; information delays
Theory of Planned Behaviour (TPB)	Behaviour is determined by behavioural intention, which emerges from the interaction of attitudes towards the behaviour, perceived social norms and perceived behavioural control. Intention is translated into action depending on perceived ability and external constraints.	Attitudes; behavioural intention; perceived behavioural control; subjective norms; perceived behavioural feasibility; expected outcomes; implementation probability; decision threshold
Social Norm Theory	Behaviour is influenced by perceived expectations and observed behaviour of others. Individuals adapt their behaviour to conform to descriptive norms (what others do) and injunctive norms (what others approve of), creating social feedback processes.	Descriptive norms; injunctive norms; peer influence; social conformity; visibility of others' behaviour; social approval; network effects; diffusion processes; reinforcing social feedback loops

Importantly, behavioural mechanisms should not be interpreted as predefined model variables. Rather, they represent generic conceptual elements that may be operationalised differently depending on the modelling approach, the level of abstraction and the research question. For example, perceived social norms may be represented as state variables, causal relationships, reinforcing feedback loops or explicit social network structures, whereas bounded rationality may be operationalised through limited information availability, heuristic decision rules or perception delays.

The selection of an appropriate modelling approach therefore depends not only on the research question but also on the intended level of behavioural representation. Qualitative systems models like Causal Loop Diagrams provide a flexible means of representing behavioural mechanisms, feedback structures and causal interdependencies without requiring precise empirical parameterisation. This structural perspective can be sufficient to understand how policies influence decision-making processes, identify behavioural barriers and reveal potential policy leverage points.

When research questions require the analysis of temporal dynamics, policy scenarios or emergent system behaviour, these qualitative representations can be translated into quantitative simulation models such as System Dynamics or agent-based models. However, quantitative representation of behavioural mechanisms is considerably more demanding because it requires empirical parameterisation of social and cognitive variables. Collecting reliable behavioural data across heterogeneous populations is resource-intensive, while differences in values, norms, preferences and decision-making styles limit the transferability of empirical findings across contexts (Schlüter et al., 2017). Furthermore, bounded rationality (Lipman, 1995), subjective perception of information and social desirability bias (Larson,

2019) introduce fundamental uncertainties that cannot be eliminated through additional data collection alone. Consequently, behavioural simulation models remain inherently exploratory, and different operationalisations of the same behavioural theory may produce substantially different model outcomes (Kwakkel & Pruyt, 2013). These limitations do not reduce the value of quantitative behavioural modelling but emphasise the importance of selecting an appropriate level of behavioural representation for the modelling purpose. Qualitative models prioritise structural understanding of behavioural mechanisms and feedback structures, whereas quantitative models enable the exploration of temporal dynamics and policy scenarios at the expense of substantially higher parameterisation effort and uncertainty. Consequently, the appropriate level of behavioural detail should be determined by the purpose of the model rather than by the availability of behavioural theories.

3 Representing decision-making and behaviour in systems models for policy evaluation

To assess how policies or coordinated policy mixes influence target-group behaviour in sustainability transformations, systems modelling provides a versatile framework to integrate decision-making and behavioural change theories. The following sections illustrate two approaches of integration: first, developing systemic decision-making models that qualitatively map the complex decision-making process of policy target groups; second, the integration of decision-making and behavioural change concepts into socio-technical (STS) (Geels, 2004), socio-ecological (SES) (Berkes et al., 2001), and socio-ecological-technological systems (SETS) (Ahlborg et al., 2019). The translation of these qualitative models into quantitative System Dynamics or agent-based simulations to explore emergent, time-resolved dynamics is discussed in the last section.

3.1 Behaviour-centred qualitative models: Systemic decision-making models

One way to model the policy impact on the target group decisions is to create systemic decision-making models where the complex decision-making process of specific policy target groups is depicted in a systems model (Schünemann et al., 2025). Systemic decision-making models based on qualitative systems mapping have the advantage to visualise the interconnected processes in human decision-making by representing behavioural mechanisms derived from established behavioural and decision-making theories.

In the following, it will be explained for a specific example how this can be managed. Schünemann et al. (2025) dedicated their work to the question of why, despite existing policy frameworks, energy retrofit dynamics in most European countries remain far below the levels required to meet climate mitigation targets. To address this challenge, they developed a systemic decision-making model that maps the decision-making process of single-family homeowners regarding energy retrofit integrating psychological, sociological and economic factors within a complex systems perspective, and thereby accounting for the systemic interdependencies that individual-level barrier analyses have thus far left poorly understood. This is achieved by developing a qualitative Causal Loop Diagram (CLD) depicted in Figure 1 whose core structure is based on the psychological Rubicon model, a framework that describes the transition between different phases in goal-directed human behaviour (Heckhausen & Gollwitzer, 1987). It divides the process into motivation, planning, action, and evaluation phases, emphasising a 'Rubicon', or point of no return, when a decision is made, shifting the focus from deliberation to goal pursuit. The focus of the model explanation centres on the pre-decisional motivation phase (Rubicon phase 1), as it describes the crucial process by which uninterested homeowners decide to dive into the topic energy retrofit. In this pre-decisional phase, the fundamental condition for action is established, based on the homeowner's cost–benefit analysis and a range of psychological factors, while the remaining three phases reflect the circumstances of homeowners in realising the retrofit and their satisfaction with the outcome, which in turn evoke important feedback loops.

Especially within the pre-decisional motivation phase, the model incorporates behavioural mechanisms derived from ten established decision-making and behavioural theories from psychology, behavioural economics and the social sciences (see Table 4). Rather than reproducing these theories individually, the systemic decision-making model synthesises their complementary behavioural mechanisms within an integrated Systems Thinking perspective, thereby providing a more holistic representation of how policies influence individual decision-making and behaviour.

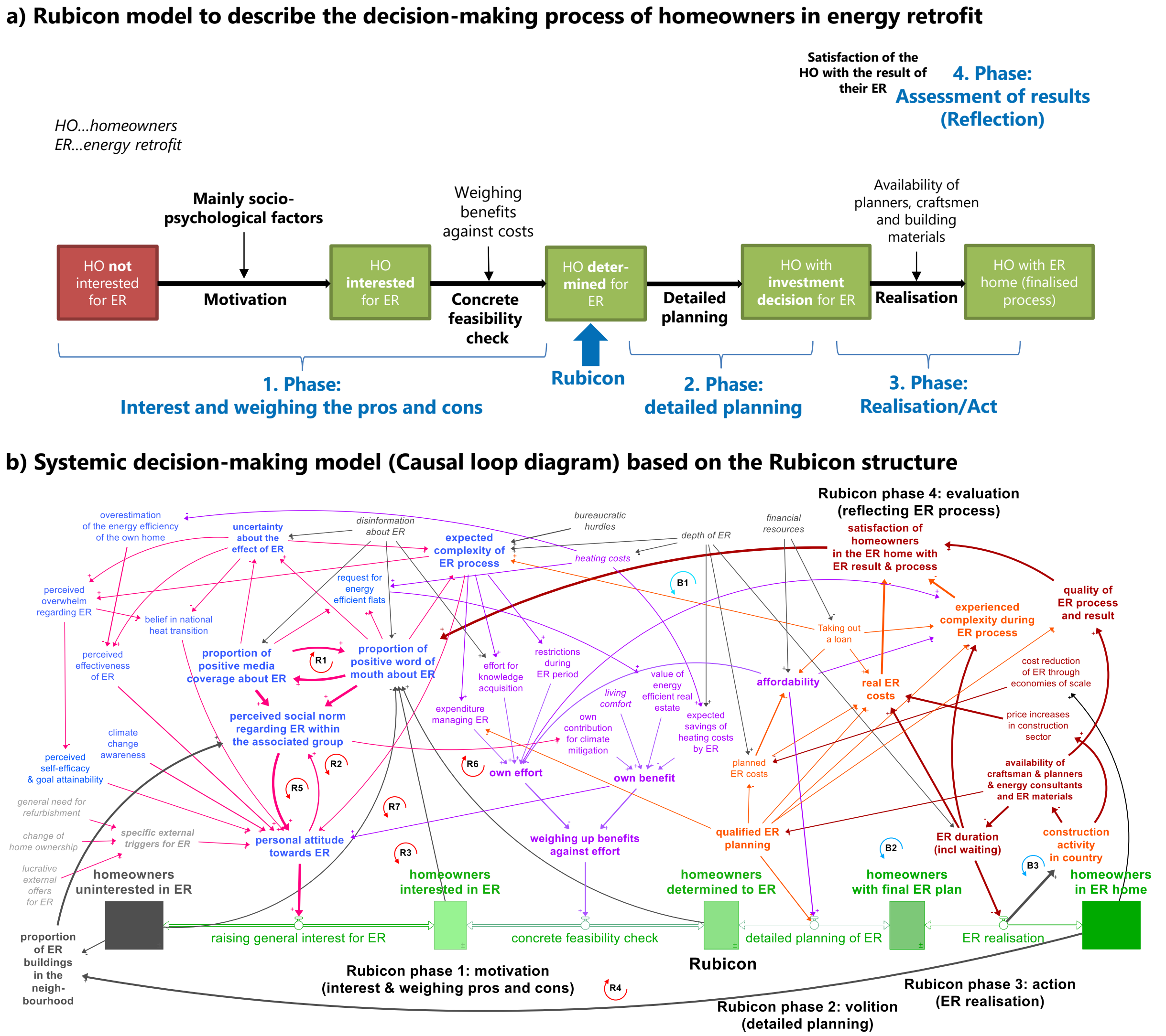

Figure 1: Exemplary systemic decision-making model describing homeowners' (HO) energy retrofit (ER) decision-making process based on the Rubicon model (taken from Schünemann et al. (2025)).

Combining this individual decision-making perspective with a systemic view, by including perceived social norms formed by media and the social environment, the model demonstrates the added value of this integrative approach. Well established theories with a specific focus on human decision-making and behavioural change could be integrated into one systemic decision-making model aiming for a more holistic description where policies are affecting the decision-making process and which feedback loops are influenced. As central outcomes, the exemplary systemic decision-making model reveals that especially media and word-of-mouth effects in the social environment have a remarkable impact on the perceived social norm about energy retrofit among homeowners and thus their decision. Because human decision-making is subject to bounded rationality and systematic cognitive biases, policies premised on purely rational actor assumptions will consistently underestimate the behavioural inertia to be overcome. Accordingly, the model implies that considerably stronger and more behaviourally informed policy interventions are required to achieve the pace of energy retrofit necessary for climate mitigation targets.

Table 4: Decision-making and behavioural theories represented in the systemic decision-making model (CLD) describing homeowners' (HO) energy retrofit (ER) decision-making process illustrated in Figure 1.

Theory	Core mechanism contributed	Primary disciplinary origin
Bounded Rationality	Decisions under limited information and cognitive constraints	Economics, Psychology
Theory of Planned Behaviour	Behaviour driven by attitudes, social norms and perceived behavioural control	Social Psychology
Social Cognitive Theory	Self-efficacy and observational learning shape behaviour	Psychology
Social Norm Theory	Behaviour influenced by perceived social expectations and peer behaviour	Sociology, Social Psychology
COM-B Model	Behaviour requires capability, opportunity and motivation	Behavioural Science, Psychology
Protection Motivation Theory	Threat and coping appraisal drive protective behaviour	Psychology
Value-Belief-Norm Theory (VBN)	Values and personal norms motivate pro-environmental behaviour	Psychology
Prospect Theory	Decisions depend on perceived gains, losses and risk framing	Behavioural Economics
Social Identity Theory	Group identity and social belonging influence behaviour	Social Psychology
Institutional Theory	Organisational behaviour shaped by formal and informal institutions	Sociology, Political Science

This systemic decision-model can also be transferred to other contexts of sustainability transformations since most variables and processes will be similar. The main benefit of such systemic models is to be developed on numerous existing decision-making and behavioural theories and concepts into one description of decision-making or behavioural change. However, for policy assessment, especially the pre-decisional phase should be analysed in more detail. Here, quantitative systems modelling approaches like System Dynamics or agent-based modelling might be suitable to capture time-resolved dynamics based on the emergent system behaviour.

3.2 System-centred qualitative models: STS, SES and SETS models including decision-making or behavioural change

A different way to integrate human behaviour is to include decision-making and behaviour change theories and concepts into systems models with a strong technical or ecological component. Such systems models belong to the socio-technological, socio-ecological or socio-ecological-technological systems. Despite their different disciplinary origins of these systems frameworks, all of them consider the social component which includes human response to changes, interventions or policies in those mixed systems. However, in contrast to the approach of developing systemic decision-making models, the focus of these models is to describe technical, ecological or ecological-technical systems where the social component is an element influencing the systems to a certain extent. Accordingly, the social dimension in those models is represented very differently, e.g. by showing the impact on human behaviour or decision making on ecological systems, or by analysing social diffusion of technological innovations. The level of behavioural detail therefore depends on the purpose of the systems model rather than on the availability of behavioural theories. To integrate the complex social dimensions into those systems properly is crucial to avoid assumptions like simplifying humans as homo economicus, deciding purely rational with full information (Burns, 1985), leading to insufficient systems understanding and questionable results. Because of the existing heterogeneity of STS, SES or SETS modelling approaches, such an integration does not follow a certain formalisation (Schlüter et al., 2017). This challenges a valid integration of decision-making and behaviour change theories and concepts going beyond simple ad-hoc assumptions. In this context, Gambardella and Lounsbury (2020) provide an annotated bibliography compiled by the System Dynamics Society's Special Interest Group on Psychology and Human Behaviour offering a comprehensive overview of approaches that integrate decision-making and behavioural concepts into Systems Thinking models (Gambardella & Lounsbury, 2020).

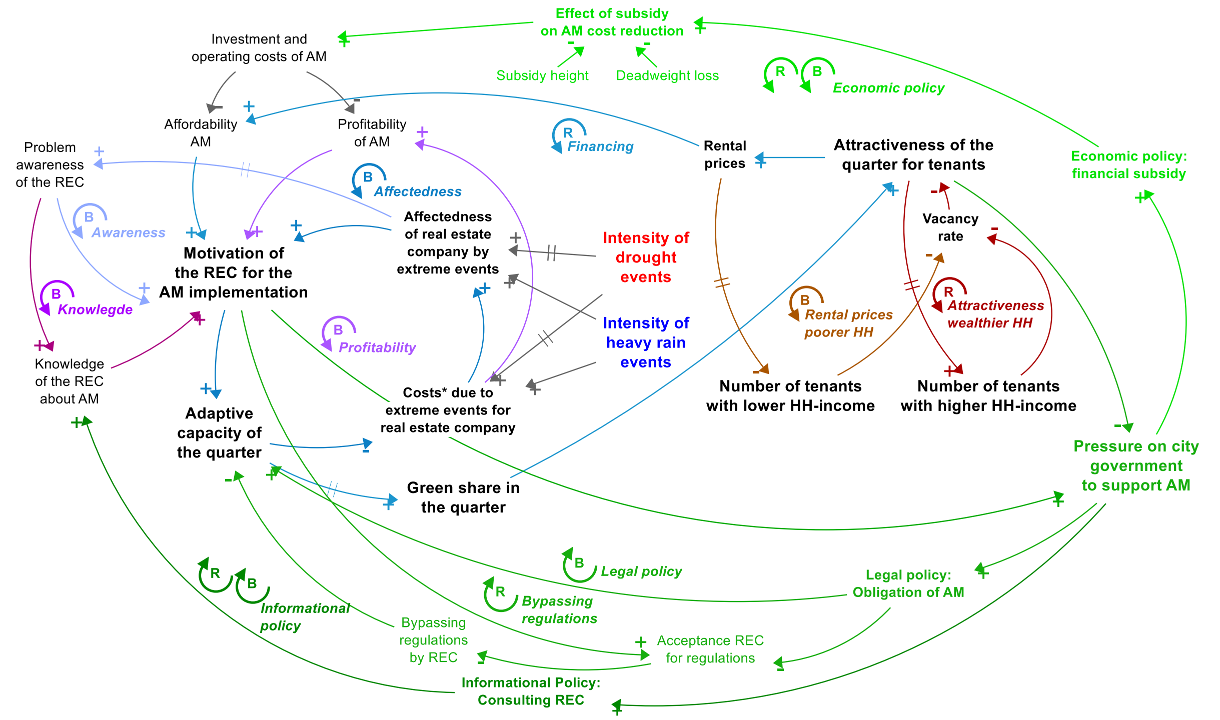

Figure 2: Exemplary CLD model describing a STS including decision-making and behavioural change elements of the landlord (REC) and the tenants regarding implementation of Sponge City measures to enhance the resilience of the quarters green share towards heat and drought. The CLD is taken from Schünemann et al., (2024).

In the following, an example for simple STS model will be discussed to show these challenges. Schünemann et al. (2024) analysed the landlord-tenant dilemma in apartment buildings by developing a qualitative CLD model for analysing the implementation of rainwater retention measures under the Sponge City concept in a multi-residential urban quarter. In this district, the landlord acts as the primary investor and decision maker regarding Sponge city measure implementation, which has an impact of the quarters green share and thus on its attractiveness influencing the tenants to stays, move in or move out of the district. The central research question in the STS models is how different policies affect the decision-making process of the building owner and the tenants and thus the dynamics of the corresponding system regarding resilient green share for heat and droughts and vacancies of apartments. Major outcomes of the simplified models are that the decision-making process of the landlord to implement Sponge City measures depend on various factors (affectedness, problem awareness, knowledge, economics), that green gentrification arises as a side-effect when the district becomes more resilient to droughts and heat because of those measures and that aligned policy mixes are needed to address these challenges. However, in contrast to the previously discussed systemic decision-making model which was designed from existing theories in behavioural science, this exemplary STS model only considers the social component by integrating crucial factors influencing the decision-making process of the landlord (affectedness, problem awareness, knowledge, economics) and the tenants (quarters' attractiveness and vacancy share, rental price). Although these factors are important elements in behavioural and decision-making theories, no explicit decision-making process is depicted in the CLD model in Figure 2 at this stage. This might be sufficient in a qualitative description of the STS to analyse where and how policies intervene in such a system by influencing or adding feedback loops (see Figure 2).

3.3 From qualitative systems thinking to quantitative simulation

The previously discussed CLDs are examples of qualitative decision-making or behavioural change representation in systems modelling in the context of sustainability transformations. While these qualitative models already provide valuable insights into behavioural mechanisms, feedback structures, and policy leverage points, quantification is only required when the research objective is to analyse time-dependent system behaviour, compare policy scenarios dynamically, or investigate emergent system behaviour. System Dynamics represents one possible quantitative extension of qualitative systems thinking models when research questions require the explicit analysis of temporal dynamics, nonlinear feedbacks or policy scenarios. For developing System Dynamics (SD) simulation based on these CLDs, the key challenge arises because the soft or social variables in the systems models must be operationalised and parameterised in mathematical form. In the conceptual CLD, variables such as actor motivation, awareness, perceived benefits, or willingness to implement adaptation measures represent important drivers of decision-making and are connected through feedback loops with economic and environmental variables. However, these variables are inherently qualitative and represent cognitive or social processes rather than directly measurable system states. As a result, they cannot be transferred directly into simulation models without additional assumptions.

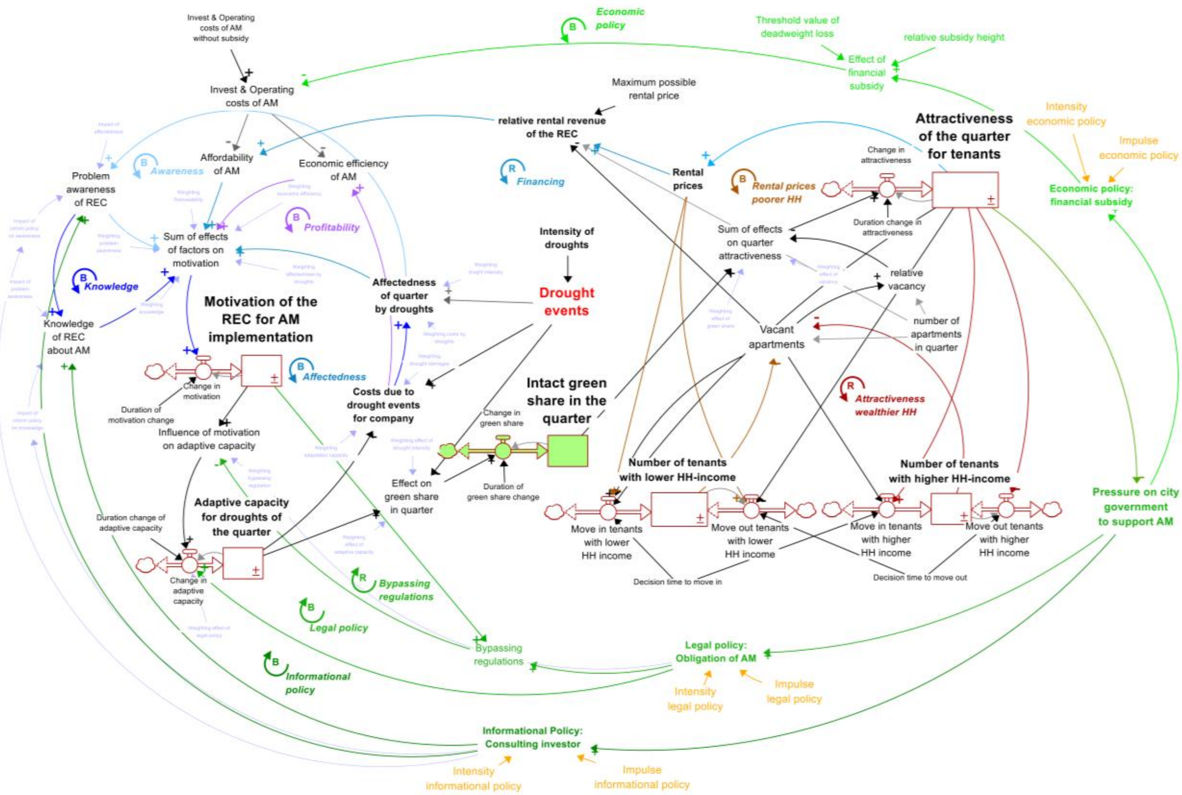

Figure 3: Exemplary System Dynamics simulation model describing an STS including decision-making and behavioural change elements of the landlord (REC) and the tenants regarding implementation of Sponge City measures to enhance the resilience of the quarters green share towards heat and drought. The image is taken from Schünemann et al., (2024).

To develop a SD simulation model based on the discussed STS of Sponge City quarter development, the behavioural mechanisms represented through soft variables of the CLD (see Figure 2) must be transferred into aggregated stock-and-flow structures and functional relationships. This is shown exemplary in the stock-and-flow diagram of the SD model in Figure 3 (Schünemann et al., 2024). For example, actor motivation or willingness to implement measures is represented as a dynamic variable that increases or decreases depending on perceived economic attractiveness, knowledge levels, and policy incentives. Policies, such as subsidies, regulations, or informational measures, affect the systems model as exogenous variables that influence these behavioural drivers by altering perceived costs, expected benefits, or knowledge about available solutions. In this way, behavioural change is not modelled at the individual level but approximated through continuous system variables that represent the average behaviour of a group of actors (e.g. real estate companies).

A key challenge in this quantification is that the parameters governing these relationships, such as the strength of policy influence on motivation or the speed at which awareness translates into implementation decisions, are rarely supported by empirical data. Many behavioural variables represent subjective perceptions, learning processes, or institutional factors that are difficult to quantify, especially when individual differences in decision-making and behaviours are considered. Consequently, such parameterisation of soft variables typically relies on literature values, expert judgement, or socio-empirical methods such as surveys or behavioural experiments. However, even if this resource- and time-consuming parameterisation is carried out with the utmost care, the quantified variables entail a level of uncertainty because future human decision-making and behavioural change under different conditions cannot be predicted with certainty. Accordingly, such SD simulations remain explorative but are able to generate a deeper systems understanding than qualitative CLDs.

Rather than replacing qualitative systems models, quantitative SD models should therefore be understood as a complementary extension for addressing specific research questions. For the case of both discussed CLDs (Figure 1 and Figure 2), it may be more reasonable to deeper investigate selected processes within the decision-making process in greater depth using more elaborated SD or agent-based modelling approaches. If, for example, participatory modelling exercises with domain experts reveal uncertainty about whether implementation knowledge, awareness, or economic constraints are the primary drivers of a given decision, it may be worthwhile to investigate that specific process more rigorously, either through socio-empirical methods or by developing quantitative systems simulation models.

Conclusion & Outlook

Representing human decision-making and behavioural change remains one of the central challenges for systems models intended to support sustainability policy design. Existing decision-making and behavioural theories provide complementary perspectives on human behaviour, yet they operate at different analytical levels, address different mechanisms and serve different explanatory purposes. Rather than integrating complete behavioural theories into systems models, this paper argues that the representation of behavioural mechanisms should be guided by the purpose of the model. Behaviour-centred models provide rich representations of decision-making processes and behavioural feedbacks, whereas broader socio-technical (STS), socio-ecological (SES) and socio-ecological-technological (SETS) systems models emphasise interactions between social, ecological and technical subsystems. *The appropriate level of behavioural detail should be determined by the purpose of the model rather than by the availability of behavioural theories.*

This distinction also highlights an important implication for the use of qualitative and quantitative modelling approaches. Qualitative Systems Thinking models, particularly Causal Loop Diagrams, already provide substantial value by making behavioural mechanisms, feedback structures and policy leverage points explicit. They facilitate interdisciplinary communication, support stakeholder engagement and help develop a shared understanding of complex sustainability challenges. When research questions require the analysis of temporal dynamics, policy scenarios or emergent system behaviour, these qualitative models can, where appropriate, be translated into quantitative System Dynamics or agent-based simulations. However, representing social and cognitive processes quantitatively remains resource-intensive and inherently uncertain, requiring careful parameterisation, empirical evidence and transparent assumptions.

The principal contribution of this paper is therefore not the proposal of a new behavioural theory or modelling framework, but a structured perspective on how behavioural mechanisms can be represented in different types of complex system models for sustainability policy assessment and design. By distinguishing behaviour-centred and system-centred modelling approaches, the paper highlights their complementary strengths and limitations and provides a conceptual foundation for selecting an appropriate level of behavioural representation according to the analytical purpose of the model.

Future research should move beyond comparing or directly integrating complete behavioural theories into systems models. Instead, greater attention should be devoted to identifying the behavioural mechanisms that are essential for representing the social component of complex sustainability systems. Such an approach would support more systematic, transparent and transferable representations of social dynamics across different modelling contexts while remaining sufficiently flexible for different policy questions and levels of abstraction.

Finally, this paper raises a broader methodological question that extends beyond the comparison of individual behavioural theories: *How should the social component of socio-technical, socio-ecological and socio-ecological-technological systems be represented in qualitative and quantitative systems models?* Addressing this challenge represents an important direction for future research and may contribute to more behaviourally informed policy design and assessment under conditions of complexity and uncertainty.

Use of AI Tools

In the preparation of this article, AI-based language assistance was employed to support the writing, editing, and structuring of the text (Claude, Mistral, ChatGPT). Specifically, the AI was used to help formulate clear, coherent sentences, improve the flow of sections, and summarize complex concepts in decision-making and behavioural science for systems modelling. All intellectual content, scientific arguments, analyses, and interpretations were developed and verified by the authors. The AI did not generate original research, data analysis, or conclusions; its role was solely as a writing and editorial support tool.

Funding

This research was funded by the Leibniz Institute of Ecological and Regional Development (IOER) within the scope of the IOER project 'DEKASYS: Decarbonisation of the German Residential Building Stock—Qualitative and Quantitative System Modelling of the Societal Motivation Processes to Increase the Energetic Renovation Dynamics and the Effectiveness of Policy Instruments'.

Literature

Ahlborg, H., Ruiz-Mercado, I., Molander, S., & Masera, O. (2019). Bringing Technology into Social-Ecological Systems Research—Motivations for a Socio-Technical-Ecological Systems Approach. *Sustainability*, *11*(7), 2009. https://doi.org/10.3390/su11072009

Ajzen, I. (1991). The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes*, *50*, 179–211. https://doi.org/https://doi.org/10.1016/0749-5978(91)90020-T

Bandura, A., & Walters, R. H. (1977). *Social learning theory* (Bd. 1). Prentice hall Englewood Cliffs, NJ. https://doi.org/10.1177/105960117700200317

Berkes, F., Colding, J., & Folke, C. (Hrsg.). (2001). *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change* (1. Aufl.). Cambridge University Press. https://doi.org/10.1017/CBO9780511541957

Burns, R. (1985). The Letters of Robert Burns. In R. Burns, *The Letters of Robert Burns* (S. 138–138). Oxford University Press. https://doi.org/10.1093/oseo/instance.00033657

Dold, M., Harper, D., Rajagopalan, S., & Whitman, G. (2025). Process, rationality and human wellbeing. *Behavioural Public Policy*, *9*(3), 485–494. https://doi.org/10.1017/bpp.2024.60

Gambardella, P. J., & Lounsbury, D. W. (2020). *Annotated Bibliography: Modeling Psychological and Sociological Dynamics*.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems. *Research Policy*, *33*(6–7), 897–920. https://doi.org/10.1016/j.respol.2004.01.015

Haddad, C. R., Nakić, V., Bergek, A., & Hellsmark, H. (2022). Transformative innovation policy: A systematic review. *Environmental Innovation and Societal Transitions*, *43*, 14–40. https://doi.org/10.1016/j.eist.2022.03.002

Heckelman, J. C. (2019). Collective Action. In J. C. Heckelman, *The Oxford Handbook of Public Choice, Volume 1* (S. 466–488). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190469733.013.23

Heckhausen, H., & Gollwitzer, P. M. (1987). Thought contents and cognitive functioning in motivational versus volitional states of mind. *Motivation and Emotion*, *11*(2), 101–120. https://doi.org/10.1007/BF00992338

Kahneman, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, *47*(2), 263. https://doi.org/10.2307/1914185

Kaufman, S., Saeri, A., Raven, R., Malekpour, S., & Smith, L. (2021). Behaviour in sustainability transitions: A mixed methods literature review. *Environmental Innovation and Societal Transitions*, *40*, 586–608. https://doi.org/10.1016/j.eist.2021.10.010

Kern, F., Rogge, K. S., & Howlett, M. (2019). Policy mixes for sustainability transitions: New approaches and insights through bridging innovation and policy studies. *Research Policy*, *48*(10), 103832. https://doi.org/10.1016/j.respol.2019.103832

Kwakkel, J. H., & Pruyt, E. (2013). Exploratory Modeling and Analysis, an approach for model-based foresight under deep uncertainty. *Technological Forecasting and Social Change*, *80*(3), 419–431. https://doi.org/10.1016/j.techfore.2012.10.005

Lane, D. C., & Rouwette, E. A. J. A. (2023). Towards a behavioural system dynamics: Exploring its scope and delineating its promise. *European Journal of Operational Research*, *306*(2), 777–794. https://doi.org/10.1016/j.ejor.2022.08.017

Larson, R. B. (2019). Controlling social desirability bias. *International Journal of Market Research*, *61*(5), 534–547. https://doi.org/10.1177/1470785318805305

Lipman, B. L. (1995). Information Processing and Bounded Rationality: A Survey. *The Canadian Journal of Economics*, *28*(1), 42. https://doi.org/10.2307/136022

Macy, M. W., & Willer, R. (2002). From Factors to Actors: Computational Sociology and Agent-Based Modeling. *Annual Review of Sociology*, *28*(1), 143–166. https://doi.org/10.1146/annurev.soc.28.110601.141117

Michie, S., Van Stralen, M. M., & West, R. (2011). The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Science*, *6*(1), 42. https://doi.org/10.1186/1748-5908-6-42

Müller-Hansen, F., Schlüter, M., Mäs, M., Donges, J. F., Kolb, J. J., Thonicke, K., & Heitzig, J. (2017). Towards representing human behavior and decision making in Earth system models – an overview of techniques and approaches. *Earth System Dynamics*, *8*(4), 977–1007. https://doi.org/10.5194/esd-8-977-2017

Prochaska, J. O., & Velicer, W. F. (1997). The Transtheoretical Model of Health Behavior Change. *American Journal of Health Promotion*, *12*(1), 38–48. https://doi.org/10.4278/0890-1171-12.1.38

Raven, R., & Walrave, B. (2020). Overcoming transformational failures through policy mixes in the dynamics of technological innovation systems. *Technological Forecasting and Social Change*, *153*, 119297. https://doi.org/10.1016/j.techfore.2018.05.008

Reckwitz, A. (2002). Toward a Theory of Social Practices: A Development in Culturalist Theorizing. *European Journal of Social Theory*, *5*(2), 243–263. https://doi.org/10.1177/13684310222225432

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Rogge, K. S., & Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy*, *45*(8), 1620–1635. https://doi.org/10.1016/j.respol.2016.04.004

Schlüter, M., Baeza, A., Dressler, G., Frank, K., Groeneveld, J., Jager, W., Janssen, M. A., McAllister, R. R. J., Müller, B., Orach, K., Schwarz, N., & Wijermans, N. (2017). A framework for mapping and comparing behavioural theories in models of social-ecological systems. *Ecological Economics*, *131*, 21–35. https://doi.org/10.1016/j.ecolecon.2016.08.008

Schrieks, T., Botzen, W. J. W., Wens, M., Haer, T., & Aerts, J. C. J. H. (2021). Integrating Behavioral Theories in Agent-Based Models for Agricultural Drought Risk Assessments. *Frontiers in Water*, *3*, 686329. https://doi.org/10.3389/frwa.2021.686329

Schünemann, C., Dshemuchadse, M., & Scherbaum, S. (2025). A systemic decision-making model for energy retrofits. *Buildings & Cities*, *6*(1), 511–526. https://doi.org/10.5334/bc.534

Schünemann, C., Johanning, S., Herold, H., & Bruckner, T. (2024). Modelling the behaviour in sociotechnical systems for policy assessment—A comparison of modelling approaches using the example of Sponge City concept implementation. *Journal of Cleaner Production*, *462*, 142722. https://doi.org/10.1016/j.jclepro.2024.142722

Simon, H. A. (2000). Bounded rationality in social science: Today and tomorrow. *Mind & Society*, *1*(1), 25–39. https://doi.org/10.1007/BF02512227

Strassheim, H. (2021). Behavioural mechanisms and public policy design: Preventing failures in behavioural public policy. *Public Policy and Administration*, *36*(2), 187–204. https://doi.org/10.1177/0952076719827062

Thaler, R. H. (2018). From Cashews to Nudges: The Evolution of Behavioral Economics. *American Economic Review*, *108*(6), 1265–1287. https://doi.org/10.1257/aer.108.6.1265

Verplanken, B., & Orbell, S. (2003). Reflections on Past Behavior: A Self-Report Index of Habit Strength[1]. *Journal of Applied Social Psychology*, *33*(6), 1313–1330. https://doi.org/10.1111/j.1559-1816.2003.tb01951.x