“History in a bottle”: Tipping dynamics in packaging systems – the case of how ~~Tipping dynamics in packaging systems: How~~ a bottle reuse system was established and then undone

Fenna Blomsma[1], Mila K. F. Ong[1], ~~Mila K. F. Ong[1], Fenna Blomsma[1],~~ Timothy M. Lenton[2]

[1] Faculty of Business, Universität Hamburg, Economics and Social Sciences, Hamburg, Germany
[2] Global Systems Institute, University of Exeter, Exeter EX4 4QE, UK

Correspondence to: Fenna Blomsma (fenna.blomsma@uni-hamburg.de)~~Mila Ong (kimchau.ong@studium.uni-hamburg.de)~~

Abstract. In this paper we investigate the initially successful transition from regional bottle reuse for mineral water to a widespread bottle reuse system in Germany as well as its subsequent destabilisation into a single use recycling paradigm – and what this teaches us about tipping dynamics in packaging systems. Our aim is to understand how tipping happens, focusing on destabilising (of the previous system) and enabling (of the new system) dynamics and the agency of business and policy to bring this about. Building on current research on positive tipping points, our case study demonstrates opportunities to create an environment for change, the role of reinforcing feedback loops in accelerating sustainable transitions, and successful interventions. However, the case also demonstrates the threat of destabilisation of newly created systems as a result of the emergence of competing technologies, in this case single-use plastic bottles. Unsuccessful efforts to stop this, included the introduction of a reusable plastic bottle and a failed policy intervention that rushed into a solution that instead accelerated the change it was designed to prevent. We close by examining what lessons can be learned from this historical case for current ongoing efforts to accelerate the transition towards a circular economy. Furthermore, based on our insights, we propose a first version of a prescriptive method that uses the positive tipping points lens as a means to develop new solutions and interventions.~~, its subsequent destabilisation, and what this teaches us about tipping dynamics in packaging systems. Our aim is to understand how the speed of sustainable change is influenced, focusing on key actors from business and policymaking. Building on current research on positive tipping points, our case study demonstrates opportunities to create an enabling environment for change, the role of specific reinforcing feedback loops in accelerating sustainable transitions, and a successful business innovation and technology intervention. However, it also demonstrates the threat of destabilisation from the emergence of competing technologies, in this case single-use plastic bottles, and what we can learn from the unsuccessful business and policy efforts to stop the decreasing market share of reusable bottles. A failed policy intervention illustrates the consequences of rushing into a flawed solution. We reflect on our findings considering current efforts to (re-)establish reuse systems as part of a transition towards a sustainable circular economy.~~

Keywords: Circular configurations, transitions, circular oriented innovation, cross-sectoral collaboration, social tipping points, systemic change.

1 Introduction

Formatiert: Überschrift 2

> *"The bottle of history holds the elixir of wisdom, but only those who pour from it cautiously can avoid the intoxication of repeating past mistakes." - Doris Kearns Goodwin*

In this work we examine what lessons can be learned from the case of the rapid rise and equally quick undoing of the German pool-bottle reuse system. With it we contribute to a better understanding of how to accomplish socio-technical paradigm shifts within relatively short timeframes, for which scholars traditionally reserve spans that are unhelpfully long in the light of many pressing societal challenges: with estimates ranging from 40–60 years for technological revolutions (Perez, 2011) up to 70 years for transitions to sustainable development and innovation (Grin et al., 2010; Gross et al., 2018).

This apparent contradiction has sparked interest in how change can be brought about faster. Socio-technical transition research (Geels et al., 2017; Meckling et al., 2015; Rosenbloom et al., 2020; Turnheim and Geels, 2013) has already highlighted the potential for rapid and non-linear system change. One such example is the reduction of coal use from 38% to 6% of UK electricity production in a mere 5 years (2012–2017) (Sharpe and Lenton, 2021). Another is Norway's EV share of car sales reaching 18% in 2015 and soaring to 79% by 2022, which is five times the global average (Bjerkan et al., 2016).

Knowledge creation to support such rapid change ranges from understanding how agency can be exercised by speeding up product innovation cycles through purposeful learning (Antikainen et al., 2017; Weissbrod and Bocken, 2017), to reconceptualising innovation systems for deliberately accelerating the pace of change (Blomsma et al., 2022) and to understanding how relatively small interventions can lead to big changes through self-propelling feedback (Lenton et al., 2022). Despite these efforts the dynamics of rapid socio-technical change, path-dependency and how a new stable state is created remains poorly understood. Comprehensive frameworks for empirically evaluating respective enabling conditions and triggers, that include deliberate intervention, have only recently become a focus (Fesenfeld et al., 2022; Lenton et al., 2022; Stadelmann-Steffen et al., 2021; Winkelmann et al., 2022). Unanswered questions remain around the interaction between systemic conditions and actor agency and learning that causes change to accelerate or tip to become self-sustaining. That is: whilst it is widely acknowledged that the transition towards sustainable systems is challenging (Bergek et al., 2023; Haddad et al., 2022; Kemp et al., 2022), it is still poorly understood how strategic action can accelerate the desired change, and how the starting conditions influence the change trajectory. And, as speed alone is insufficient if the new state can be easily reversed – such failures representing a waste of time, resources and motivation – more insight is also needed into how change can be made to endure (Sharpe & Lenton, 2021).

This knowledge gap complicates current ongoing transitions where a speedy and lasting change is desirable, such as the circularity ambitions set for key sectors within the EU (European Commission, 2020). The packaging sector is illustrative in this regard: the goals are ambitious both in terms of scope and time. For example: according to the current proposal for the Packaging & Packaging Waste Regulation (PPWR) countries must create deposit return schemes for metal and single-use plastic beverage containers with a 90% collection rate target by 2029 (European Commission, 2022). But this knowledge gap means there is little guidance on how to go about these efforts and increase the chance of success. Moreover, there is a risk of repeating previous mistakes as many so-called new solutions are reinventions or adaptations of solutions that were used in the past, but which were ousted by linear alternatives (Blomsma et al., 2022). Think, for the packaging sector, of the current reintroduction of reuse systems for take-away consumptions (Eunomia, 2023) or the product redesign in the form of soap bar alternatives to liquid shampoo and shower products that aim to replace two or more single-use bottles (Foamie, 2024) – much reducing packaging and shipping needs. With many such options for delivering goods and services with varying levels of sustainability, the question of how one system is introduced and is made to persist or perish, and how this interacts with other solutions, is more relevant than ever.

For this reason, in this research, we focus on the interplay of destabilising (of the previous system) and enabling (of the new system) dynamics, balancing dynamics and the role of business actors and policymaking in driving change. We investigate this through a historical case study of the tipping into a nationwide bottle reuse system in Germany, and the later tipping away from it into a single-use bottle regime. This case was chosen because of the quick tipping towards a state that is similar to what is envisioned for current circular economic efforts in the domain of packaging, but also its subsequent failure to stabilise that state. Our aim with this is to understand how to operationalise the Positive Tipping Points framework as a guiding framework for such ongoing change: what guiding questions to ask, and what risks or pitfalls to be on the lookout for - so that current change efforts may be better designed.

The paper is structured as follows. Section 2 introduces the theoretical framework of temporal tipping dynamics in socio-technical transitions and our research focus. Section 3 outlines our research design. Section 4 presents our findings regarding two phases: first the successful tipping to a widespread reuse system (1950–1985), and then the subsequent tipping away from the established reuse system (1985–2010), followed by recent developments. Section 5 discusses the insights derived from this case study, and Section 6 sums up and concludes.

~~To affect changes that involve socio-technical paradigm shifts, scholars traditionally reserve long time frames: with estimates ranging from 40–60 years for technological revolutions (Perez, 2011) up to 70 years for transitions to sustainable development and innovation (Gross et al., 2018; Grin et al., 2010). This stands in stark contrast with societies needing urgent action on multiple pressing sustainability challenges, such as equality, education, resource scarcity, environmental degradation, pollution, and global warming.~~

~~This apparent contradiction has sparked interest in how positive change can be brought about faster. Socio-technical transition research (Geels et al., 2017; Turnheim and Geels, 2013; Rosenbloom et al., 2020; Meckling et al., 2015) has already emphasised the potential for rapid and non-linear system change. Other work in this area ranges from research into fast product innovation cycles guided by purposeful learning (Weissbrod and Bocken, 2017; Antikainen et al., 2017), to reconceptualising innovation systems for deliberately accelerating the pace of change (Blomsma et al., 2022), to attempts to understand how relatively small interventions can lead to big changes through self-propelling feedback (Lenton et al., 2022).~~

~~However, the dynamics of rapid socio-technical change remains poorly understood. Comprehensive frameworks for empirically evaluating respective enabling conditions and triggers have only recently become a focus (Stadelmann-Steffen et al., 2021; Lenton et al., 2022; Fesenfeld et al., 2022; Winkelmann et al., 2022). Unanswered questions remain around the interaction between systemic conditions, actor agency and learning that causes change to accelerate or *tip* to become self-sustaining. How to set direction towards sustainable outcomes needs addressing as current work has not advanced beyond recognising directionality challenges (Haddad et al., 2022; Bergek et al., 2023; Kemp et al., 2022). Equally, more research is required to determine how change can be made to endure (Sharpe and Lenton, 2021).~~

~~It's important to mindfully approach speed, as it may not always be beneficial. A speedy solution can be implemented, but still not address a problem due to it not being fit-for-purpose (Sterner et al., 2010), or inadequately implemented (Howes et al., 2017). A fast solution can fail to endure or it can cause larger problems due to not engaging with other important aspects of the initial problem (Braun, 2002). Thus, mindlessly pursuing speed could ironically result in losing momentum: when the proposed change does not materialise as desired, resources may be unavailable for another attempt. Disillusionment may grow with calls for discarding the solution altogether, even when it was not the solution itself that was flawed, but rather the manner of its implementation (Howes et al., 2017). For example, the revision of eco-energy-labelling in Germany to accommodate industry demands unintentionally diminished the effectiveness of a well-established labelling scheme by introducing new~~

~~rating categories. The flaw was not the idea of modifying the labelling scheme, but the failure to simplify the implementation to successfully influence consumer choices (Heinzle and Wüstenhagen, 2012).~~

~~Hence, in this research we ask: "*What are the tipping dynamics that can bring about fast and sustainable change – and how can it be made to last*?". Our focus lies in examining the interplay between systemic conditions, business actors and policymaking in driving change. We investigate this through a historical case study of the tipping into a nationwide bottle reuse system in Germany, and the later tipping away from it into a less sustainable single-use bottle regime. This case was chosen because of the abrupt tipping towards a sustainable state[1], but also the subsequent failure to stabilise that state. The aim is to improve the understanding of tipping dynamics, in particular those aimed at a rapid transition from a linear to circular economy. It is acknowledged, that the superiority and efficiency of particular circular strategies are highly dependent on various contextual factors and have been subject of other academic work, although it is suggested that further research is still needed to reach academic consensus (REF).~~

~~A comprehensive assessment of the environmental impacts of reuse systems and comparison with other circular strategies like recycling is beyond the scope of this project. Therefore, this research endeavour is specified on gaining a deeper understanding of the transition processes associated with the aimed for implementation of *reuse systems* as *one* alternative circular approach for sustainable packaging systems.~~

~~1.1 The case study~~

~~The selection of bottle reuse systems as a case study is predicated on the presence of substantial scientific knowledge and a seemingly greater consensus regarding the performance of reusable bottles in comparison to single-use counterparts. Additionally, the bottle reuse system is distinctive due to its scalability and enduring presence over an extended period.~~

~~Reuse systems for bottled beverages can be categorised into individual, open and closed systems (UBA, 2010?). Individual systems consist of brand-owned, bespoke standardised bottles exclusively used by the same brand. Open systems utilise standardised bottles that are shared by several companies, but are not centrally organised. For closed systems standardised pool bottles that are owned and centrally managed by one entity are available for use by all companies participating in the pool~~

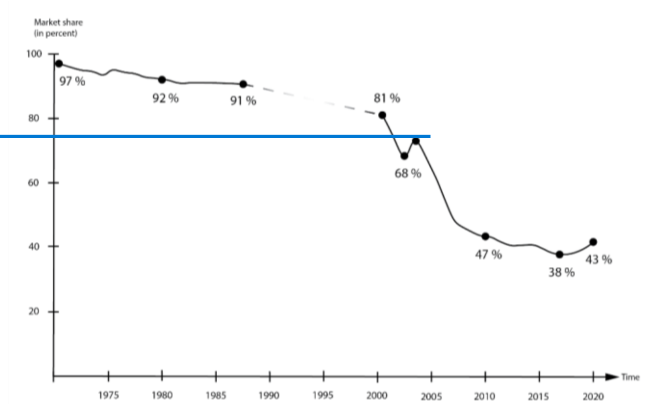
~~[1] In this study we do not include impact as measured through LCA or Carbon-equivalent measures. There is little historical data to draw from and current metrics are not well equipped to provide a nuanced insight into this. Instead, we assume that when designed well, sufficiently mature and operating at scale, reuse systems have the potential to have less impact than single-use, disposable packaging due to the resource and energy savings they represent. We invite further work on the impact assessment of both systems.~~

~~system. Typically, all of those reuse systems rely on location-based returns at retailers, although a few pick-up service providers are emerging in the market. A closed pool system is considered as most efficient, as … (Economies of reuse).~~

~~The reuse pool system for mineral water bottles in Germany is well-established as the biggest reuse system in Europe and unique in its effectiveness and comprehensive scope. It is organised and managed by a business cooperative called *GDB* (*Genossenschaft Deutscher Brunnen*) and became successful with the introduction of a 0,7 litres standardised pool bottle in 1969, that has remained unchanged since (Fig. 1). Reusable bottles held a relatively stable market share of over 80 % for three decades (1970–2000). Their environmental effectiveness is showcased by the high circulation rate of the bottles: They can be reused 40–50 times with average transportation distances of 260 km (UBA, 2016; DUH, 2014a, DUH, 2014b). While environmental evaluations cannot deliver absolute certainty and are contingent upon various factors, a broad consensus exists on the sustainable breakeven point of reusable bottles to achieve less environmental impact then the single-use alternative (in terms of GHG emissions, water use, material use, and waste generation), which is estimated to be reached within 3–10 circulations (DUH, 2014; Coelho et al., 2020) and a transport distance of less than 500 km (EMF, 2023; UBA, 2016; Coelho et al., 2020). The pool system ensures that the bottles are usually transported to the closest participating mineral water company and do not need to be returned to the original bottling company. The bottles are owned by the cooperative and lent to their business customers, noting that the vast majority of those hold an ownership stake as members of the cooperative (GDB, 2023d).~~

~~**Figure 1: The reusable glass pool bottle. Two rings (in the middle and at the bottom) function as "shock absorbers" to prevent breakage in the filling and cleaning process. The pearl-like patterns at the bottle neck expresses freshness while enabling a good grip (Bielenstein, 2019).**~~

~~While historically reuse was a necessity driven by scarcity and resource constraints, with the advent of mass production and consumption, the focus shifted from reuse to disposability (König, 2019). This also affected the beverage industry with the introduction of single-use plastic bottles, leading to a destabilisation of the dominant reuse system with a rapidly decreasing market share of reusable bottles from over 80 % to around 40 % in the decade from 2000 to 2010 (Fig. 2).~~



~~**Figure 2: Market share of reusable mineral water bottles (UBA, 1983, 2022)**~~

~~Today, the bottle reuse system coexists alongside a dominating single-use plastic bottle recycling system. While a deposit for single-use bottles (for beer, water, and soft drinks) was made mandatory in 2003 as a political intervention to stabilise the reuse market share, this only produced a temporary improvement of the reuse market share before a precipitous fall resumed.~~

~~We draw insights from these developments by investigating enabling and destabilising dynamics, identifying the feedback loops and interventions that propelled change and those that (temporarily) maintained stability to learn about business and policymaking opportunities for rapid change. We then reflect on what our findings mean for current efforts to (re-)establish and stabilise reuse systems for packaging, such as emerging industry initiatives and the EU Circular Economy agenda (European Commission, 2020). Our study also provides insight into the development of circular configurations – situations where two or more circular economy strategies interact (Blomsma et al., 2023), in this case reuse and recycling strategies that influence each other strongly over time with clear conflicts between them.~~

~~The paper is structured as follows. Section 2 introduces the underlying theoretical framework of temporal tipping dynamics in socio-technical transitions. Section 3 outlines our research design. Section 4 presents our findings regarding two phases: first the successful tipping to a widespread reuse system (1950–1985), and then the subsequent tipping away from the established~~

~~reuse system (1985–2010), followed by recent developments. Section 5 discusses the broader insights derived from this case study, and Section 6 concludes.~~

2 Theoretical framework

2.1 Socio-technical transitions and how to influence the pace of change

Sustainability transitions refer to the deliberate and systemic shifts in societies, economies, and industries towards more sustainable and environmentally responsible practices, technologies, and systems (Geels, 2011; Smith et al., 2005; Stirling, 2009). Transitions typically consist of many small, cumulative developments that culminate – over time – in the emergence of a new regime: that is, a different way in which things are done. Although this may be accompanied by phases of acceleration, the overall timeline that is the current consensus among scholars – ranging from 40 to 60 years – is too long to achieve targets like the SDGs and Paris Agreement (Gross et al., 2018; Grin et al., 2010; Kondratieff and Stolper, 1935), which stipulate that radical emission reductions of 7,6 % per year needs to be accomplished by 2030, affecting an absolute reduction of 55% compared to 1990.

Luckily, there is also evidence that change can be accelerated by taking strategic action (Sovacool, 2016; Victor et al., 2019) and that systems can be 'tipped': change not only accelerates, but becomes self-sustaining (Lenton, 2020). Different 'tipping' mechanisms have been identified that each emphasise a different aspect of change. A well-known example of this is the theory of Diffusion of Innovations (Rogers, 1962), or diffusion for short. This theory puts the spotlight on the user and states that a critical mass threshold exists that, when reached, makes other users more likely to adopt an innovation. An alternative model (Arthur, 1989) identifies how increasing returns, path dependency, and feedback loops create conditions where systems evolve in a self-reinforcing manner. Arthur demonstrates these effects for technology: where technologies that achieve early adoption benefit from increasing returns leading to 'lock-in' despite superior options being available. Another example is the coordination game by Kandori and colleagues (1993) who describe how network effects lead to situations where increasing numbers of individuals adhere to a norm or behaviour they gain more by adhering to it then by deviating from it – thereby amplifying the positive effects and attractiveness of coordination. In these models the initial change creates the conditions for amplification, which then leads to significant and often accelerating change.

Although such tipping mechanisms have explanatory capacity their synthesis and integration into action-oriented management frameworks is still limited (Geels and Ayoub, 2023). The actions prescribed by transitions management (Loorbach, 2007), strategic niche management (Schot and Geels, 2008) and Technological Innovation Systems framework (Hekkert et al., 2007), for example, are (in our view) for a large part inspired by and derived from diffusion. To better understand how to bring about tipping, a richer and more comprehensive picture is needed as to the differing roles of these different dynamics, how they interact, what concrete interventions trigger them, the influence of different starting conditions as well as what barriers and pitfalls exist. And whilst the first steps towards synthesis have further refined the interacting dynamics between techno-economic developments and core actor groups (Geels and Ayoub, 2023; Lenton et al., 2022) more empirical work is needed. For this reason, we undertake a historical case study looking at the agency exercised by business and policy – using one of the most comprehensive synthesis efforts of tipping mechanisms to date: the Positive Tipping Points (PTPs) framework.

2.2 The Positive Tipping Points framework

The Positive Tipping Points (PTPs) framework (FOLU and GSI, 2021; Lenton, 2020; Lenton et al., 2022; Sharpe and Lenton, 2021) is the antonym to the negative climate tipping points that are driving and accelerating climate change (Lenton et al., 2019). Starting from systems thinking and Meadows' 'leverage points' framework (Abson et al., 2017; Meadows, 1999) it has evolved into a framework that synthesises different tipping point models alongside interventions for different actors to trigger tipping dynamics (FOLU & GSI, 2021; Lenton et al., 2022). The PTPs framework highlights the importance of creating enabling conditions (e.g. price reductions or shifts in social norms) before a small perturbation can trigger a socio-technical tipping point. For example, Tesla's significant investment in electric vehicles and subsequent government support through tax credits has accelerated the adoption of electric vehicles, reduced greenhouse gas emissions, fostered further technological innovation in battery storage, and catalysed broader systemic changes towards sustainable urban mobility.

PTPs provide insight into how a system can be deliberately tipped in a more desirable direction (Lenton et al., 2022). Specific actions, behaviours or interventions can (separately or combined) reach a critical threshold (Dakos et al., 2015; Kopp et al., 2016) that trigger transformative system-wide change (Otto et al., 2020). That is: a system 'tips' from one state to another through making the previous state unstable, after which strong positive feedback mechanisms take over to amplify the effects of the small change(s) resulting – in a relatively short timeframe – in a fundamental shift towards a qualitatively different quasi-stable state or new dynamic equilibrium (see Fig. 3). Once initiated, these dynamics can be abrupt and – sometimes, but not always – be difficult to reverse – see Figure 1 (bottom). In this figure the depth of the valley and the height of the hill represent the stability of the current system and, consequently, the difficulty to bring about a new system state. Note that this diagram is a state-space: it represents the transition from one state to the next and is not indicative of time or desirability – and the direction can be from left to right, or the reverse.

In some cases, tipping in one domain may trigger a further chain reaction of change across sectors and scales, in a positive tipping cascade (Geels & Ayoub, 2023; Sharpe & Lenton, 2021). Lenton et al. (2022) advance the operationalisation of this framework in a non-exhaustive list that links system conditions, reinforcing feedback mechanisms and interventions or actions that can be taken to trigger PTPs – see Figure 1 (bottom).

Thus far, the framework has been applied to food and land use systems – with a focus on guiding actors in triggering tipping points across a limited number of transitions (FOLU & GSI, 2021). This has provided initial insights into the adoption of renewable energy and electric vehicles - developing a socio-technical transition perspective that highlights significant actor reorientations (Sharpe & Lenton, 2021; Geels & Ayoub, 2023), and policy changes that prioritise environmental protection - providing a procedural synthesis to streamline the identification and coordination of agent capacities required to implement transformative solutions (Tàbara et al., 2018; Fesenfeld et al., 2022). Other previous work, through expert elicitation, also identified potential social tipping interventions in subsystems like human settlements, financial markets, and education (Otto et al., 2020). Here, social tipping elements (STEs) represent specific subdomains of the planetary social-economic system where disruptive changes can lead to a fast reduction in greenhouse gas emissions, making them a crucial component of positive tipping points in the transition to carbon-neutral societies.

In this current research, we take up two areas for further development for the PTPs framework with the aim to operationalise it for better understanding – and steering of – current developments: 1) the explicit consideration of destabilising and enabling feedback loops in order to create insights into path-dependency, and 2) a more explicit focus on the role of business and policy makers in tipping dynamics. More on these in the following sections.

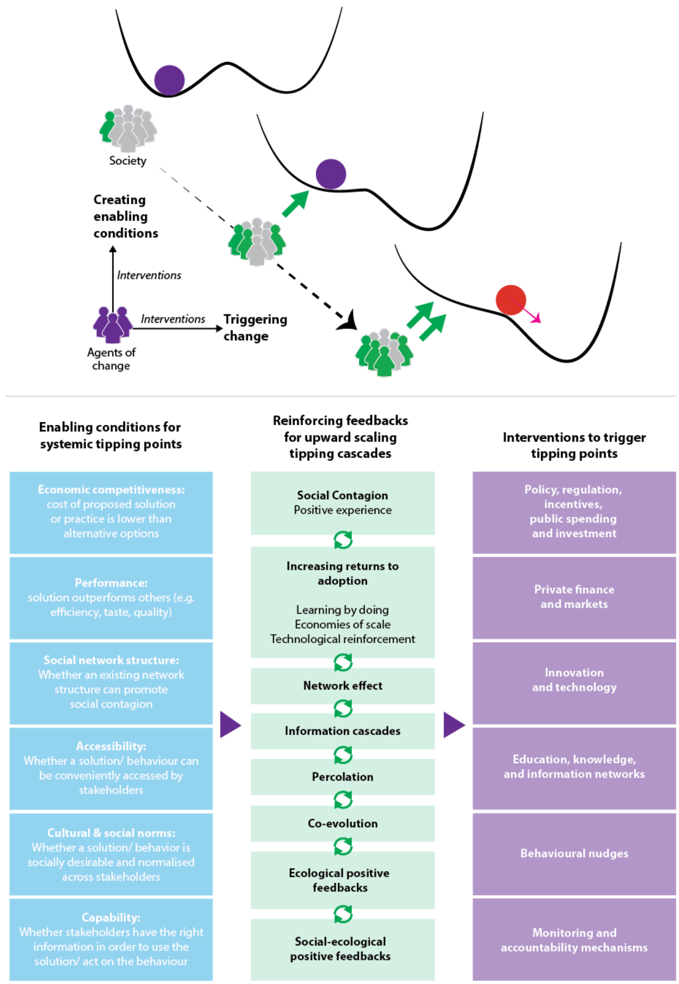


Figure 1: Top: a dynamical systems conceptualisation of positive tipping points (Lenton et al., 2022). Bottom: summary of framework for triggering positive tipping points, adapted from Lenton et al. (2022) and FOLU and GSI (2021).

2.3 Destabilising, enabling & balancing feedback loops: on path dependency and (in)stability

To bring about change two things need to happen in the PTPs framework. One, a new alternative system state emerges: in terms of the PTP state-space this means that a new valley is created. Second, the current system state becomes less stable. That is: the initial valley becomes shallower relative to the new one. It is these two concurrent developments that contribute to 'tipping.' The former has traditionally received the most attention within research on change, such as the work on adoption already mentioned above and the body of work derived and inspired by this within transition science and other work related to the S-curve in other domains (Foster, 1986; Chandy and Tellis, 2000; Christinsen, 1992; Kuhn, 1962).

However, decline – the shift in 'state space' that means that new constraints assert themselves, making old solutions obsolete – is less well understood. A thread of research exists that shows that not only do new solutions emerge, but established solutions need to decline to 'make space' for the new. Frameworks such as Panarchy (Gunderson and Holling, 2002) conceptualise this within ecology and socio-ecological change, and other work explores this idea within social transformation and organisational change – e.g. Two Loop change (Wheatley and Frieze, 2011) and the x-curve (Collins, 2008), and paradigm change - e.g. the Wave-S model (Blomsma et al., 2022). These frameworks have in common that they feature a downward curve or trend of an established solution – which may involve repurposing and exaptation (that is: innovation).

Understanding decline provides complementary insights into change as it puts the focus on what went before - and therefore puts a spotlight on path-dependency as well as (in)stability of resulting solutions. However, the interplay of destabilising (of the previous system) and enabling (of the new system) dynamics, as well as the role of balancing dynamics have to date received little (explicit) attention within the PTP work. Therefore we explore this and ask how can we understand the dynamics of decline within the PTP framework such that the influence of different starting conditions as well as the stability of the resulting change can be brought into view?

2.4 The role of business and policymakers as key actor groups – in success and failure

Existing PTP case studies tend to focus on significant changes in socio-technological systems from a macro-social perspective, there remains a need to better understand agency from the perspective of specific societal actors as well as how failure to make a new system state endure arises from their interactions. Specifically, we focus on the interplay of policy and business. Unlike past transitions that were primarily driven by emergent commercial opportunities, sustainability-oriented transitions are aimed at addressing persistent environmental and societal issues (Geels, 2011). This requires changes in, for example, taxes, subsidies, regulations and infrastructure – often the domain of policy. But it also requires changes in innovation practices, such as embracing and embedding sustainable principles in production and consumption practices, ranging from design to sourcing, from production to marketing, and from retail to revalorisation – often the domain of business (Fischer and Newig, 2016). It is therefore necessary to both navigate politics as well as involve and reorient firms to accomplish a qualitative change in systems.

This can be challenging for a number of reasons. For one, as different stakeholders control different parts of the system that will need to be aligned there is a coordination cost. Successful collaboration, for example, means that organisations exhibit proactive, solution-oriented cooperation and adaptability – supporting and strengthening the transition; whilst a lack of alignment means that entities pursue conflicting agendas and resist change – resulting in a waste of resources and potentially putting up a barrier for future efforts.

Second, tensions will need to be resolved that arise from varying and sometimes conflicting interests and perspectives on the directionality of sustainability transitions (Stirling, 2009), the merits or drawbacks of specific solutions, and how to arrive at goals. Such tensions can be resolved when, for example, stakeholders engage in constructive dialogue and consensus-building processes – enabling change; or they can cause inertia or failure when, for example, parties insist on rigid positions and prioritise short term gains over long-term solutions. In other words: both in enabling as well as obstructing change business actors and policymakers are pivotal agents of change, and their interactions can significantly impact the scope and speed of transformative change.

In order to accelerate systemic change an improved understanding of the interplay of the actions of policy and business in the context of systems is needed. That is, how these agents act to create the forces to propel or inhibit change within systems – or: what to do and what not to do. Specifically, with this work we improve the resolution of PTPs by understanding how actions of policy and business set positive feedback loops in motion or how they inhibit them. For this reason, we analyse the role of these actors in creating enabling and destabilising dynamics.

In the following historical case study we thus ask the sub-questions: Which tipping dynamics can be identified in this case that triggered or impeded the acceleration of change? What destabilising, enabling and balancing feedbacks can be seen? How can business and policy influence these tipping dynamics?

Next, we explain the case that was selected and our method for analysing it.

3 Research Design

3.1 The case study

Mineral water has long since had a prominent place in German culture, resulting in a robust industry with numerous companies vying for consumer preference. Whilst this includes soft drinks, the focus here is on mineral water - carbonated and noncarbonated. Our focus lies on the developments in West-Germany.

The use of the industry's key asset – its bottles – forms an important part of how it operates. Organised as a reuse pool-system, the reuse of the bottles is – to date, as measured by fillings per year (6 billion) and circulating reusable packaging units (1.2 billion) (UBA, 2022b) – the biggest reuse system in Europe and unique in its effectiveness and comprehensive scope according to the Genossenschaft Deutscher Brunnen (GDB, 2023c): the business cooperative who organises and manages it. This system became successful with the introduction of a 0,7 litre standardised pool bottle in 1969 called the 'pearl bottle,' which has remained unchanged since (see insert in Fig. 1). Although other reusable bottles did exist, this bottle was adopted nearly industry wide initially (Bielenstein, 2019), and currently still makes up 70% of all reusable mineral water bottles (GDB, 2023a).

This system is characterised by a high circulation rate: the bottles can be reused 40–50 times with average transportation distances of 260 km (DUH, 2014b, 2014a; UBA, 2016). It can therefore be expected that this system has less environmental impact than single-use alternatives: the sustainable breakeven point (in terms of GHG emissions, water use, material use, and waste generation) is estimated to be reached within 3–10 circulations (Coelho et al., 2020; DUH, 2014b) and a transport distance of less than 500 km c (Coelho et al., 2020; EMF, 2023; UBA, 2016)[2]. The short transport distance is accomplished by transporting the bottles to the closest participating mineral water company where possible. This as opposed to returning it to the original bottling company. The bottles are owned by the cooperative and lent to their business customers, the vast majority of which hold an ownership stake as members of the cooperative (GDB, 2023b).

This case was selected for generating insight into how actors influence PTPs because of the rapid changes it has seen over the years and the prominent role of both business and policy. When pool reuse was introduced there was an almost industry-wide adoption within a year with a relatively stable market share of over 80% for the following three decades (1970–2000). Later,

[2] Note that although we assume, for the purposes of this study, that a positive environmental impact can be expected of a reuse system, that our focus here is on the transition from one system state to another and that we consider the question of (absolute) impact one that lies outside the scope of this study, the more so as it is the area of active academic debate. As such, we use the 'positive' in the Positive Tipping Points framework in a technical sense as opposed to a normative sense, as in: reinforcing, self-perpetuating change.

however, with the advent of mass production and consumption, the necessity of reuse gave way to single use (König, 2019). This meant that single-use plastic bottles were introduced which rapidly destabilised the reuse system: its market share fell from over 80 % to around 40 % in the decade from 2000 to 2010 (Fig. 2). Today, the bottle reuse system coexists alongside the dominant single-use plastic bottle and recycling system.

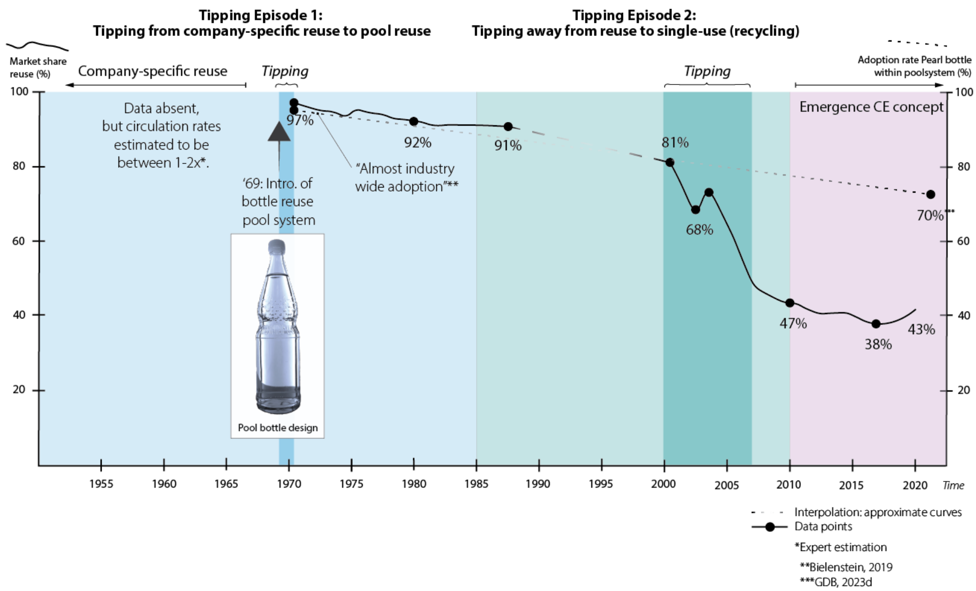


Figure 2: Market share of reusable mineral water bottles (UBA, 1983, 2022a) and the (approximated) adoption rate of the pearl bottle (Bielenstein, 2019). Image insert: The reusable glass pool bottle. Two rings (in the middle and at the bottom) function as "shock absorbers" to prevent breakage in the filling and cleaning process. The pearl-like patterns at the neck of the bottle expresses freshness while enabling a good grip (Bielenstein, 2019).

3.2 Data collection and analysis

To assess this case study, we used qualitative content analysis (Gioia, 2021). The basis for our analysis is a comprehensive timeline of events that was constructed using secondary data, incorporating relevant information from the political and economic context, and developments within the mineral water industry – with a focus on how policy and business shaped the outcomes. Industry information was sourced from historical reports of a leading mineral water company Gerolsteiner (Lippert et al., 2012; Schuck, 2015) and the industry cooperative GDB (Bielenstein, 2019), supported by an expert interview. Additional insights were drawn from existing literature on the history of the mineral water industry (Eisenbach, 2004), as well as complementary literature on the German history of waste (Kleinschmidt and Logemann, 2021; König, 2019). To enrich the analysis, archival documents from the Federal Archive in Germany, specifically those relating to the beverage industry from 1980 to 1990, were consulted. Key performance indicators like market shares and circulation rates were extracted from reports issued by the German Federal Environmental Agency (UBA, 1983, 2010, 2016, 2022).

Based on this timeline two tipping episodes were identified: 1) tipping towards the pool-bottle system covering the period between 1950-1985, with tipping happening between 1969-1970, and 2) tipping towards the single-use and recycling system between 1985-2010, with tipping between 2000-2007[3]. For these two periods an overview was created that covers the enabling conditions, feedback mechanisms and relevant interventions by both business and policy makers using deductive qualitative content analysis (Goia, 2021). Text segments from the various sources were coded according to the enabling conditions and the feedback mechanisms categories as identified within the PTP framework (Lenton et al, 2022) - see Table 1. An example of a feedback loop is the network effect that reinforced tipping towards a new system as the attractiveness of participating in the new system increased the more other companies joined.

			Aggregate dimensions		
Data	**First order code (Paraphrase)**	**Second order code (Generalization)**	**Enabling conditions**	**Reinforcing feedback loops**	**Interventions**
[...] This was made possible by the mineral water companies' realisation that many pressing problems could only be solved together and with the help of a strong cooperative. The members were even ready to pay a substantially higher fee, since they profited from the work of the cooperative [...] (Eisenbach, 2004, p. 267)	Successful collaboration of the cooperatives, due to the realisation that many challenges are shared and can be solved more easily together.	Realization of the importance of collaboration with other companies for a higher resilience of the industry and consequently their own company.	Economic competitiveness	Social contagion, Network effects	/

Table 1: Example of data coding

Additionally, the feedback mechanisms are assigned as part of either destabilising (magenta), enabling dynamics (green) or balancing (blue), and assigned to (or in between) the curve(s) dedicated to the timeframe they exerted influence (indicative times indicated in the purple balls) – see Figures 4 and 5. In this way, the overview emphasises the dynamics and their interactions. Specifically: destabilising dynamics refer to those forces that undermine the validity of current practices and solutions: what is 'tipped away' from. For example: The economic inefficiency of company-specific bottle reuse and material

[3] In reality, there exists some overlap between these two periods in the sense that the conditions that enabled the second episode already started to change towards the end of the first period. For reasons of simplicity and brevity we strictly separate the two episodes.

and energy shortages meant this solution was no longer fit-for-purpose. Enabling dynamics are those that specifically push towards the next paradigm as opposed to another: what is ‘tipped towards.’ For example: in Tipping Episode 1 the existing reliance on reuse practices and the promising increasing returns of adopting a centrally organised solution enabled tipping to a pool reuse system. Balancing dynamics, for example, could be recognised in dynamics that stabilised a certain state, like the high costs of switching to a new technology. Lastly, the interventions that enabled the change - where agency was exercised - are furthermore assigned to either business and policy.

4. Results: The historical development of the German bottle reuse system

Before discussing the two tipping episodes, we briefly discuss the case context and the starting conditions pre-tipping. Acronyms mentioned below refer, respectively, to enabling conditions (EC), reinforcing feedback loops (R), balancing feedback loops (B) and interventions (I). Numbering of these elements is continuous across both episodes to be able to distinguish clearly between them. Numbering follows the images (Fig. 4 and 5), which may differ from where developments are featured in the text for clarity and brevity. Additionally, interventions are assigned to an actor group: e.g. business (b) or policy (p).

4.1 The case context: the starting situation

Germany’s rich geological diversity provides access to various natural springs, allowing mineral water to gain a prominent place in German daily life as a staple beverage. Additionally, the country's strict regulations ensure high-quality standards for the production of mineral water, fostering a competitive market. In this industry, like in many others, reuse had long been the standard before the “throwaway mentality” emerged. This was due to scarcity-driven economies, that made it necessary to maximise the exploitation of available resources and goods by reusing, reutilising and repurposing them for as long as possible (Denton and Weber, 2022). Consequently, bottle reuse was a common procedure, i.e. social norm (EC1), to save costs for mineral water companies. However, large scale reuse systems did not exist due to a lack of infrastructure. Before the first tipping episode, every mineral water company used its individually shaped, company-specific bottles for reuse – leading to long, laborious, and expensive exchange and return processes – or directly discarded them through costly glass recycling (Eisenbach, 2004).

Earlier efforts to change this had failed: already in 1875 and again in 1950 efforts were made to implement a more efficient solution in the form of a standardised bottle design. The first effort suffered from a lack of leadership and difficulties in aligning prospective partners, whilst the second effort stumbled over unsurmountable technical difficulties - and both efforts were abandoned (Eisenbach, 2004). However, after the end of WWII, enabling conditions changed which paved the way for a crucial business intervention that led to near-industry wide adoption of the pool reuse system, and which set the sequence of tipping episodes in motion – see Fig. 3.

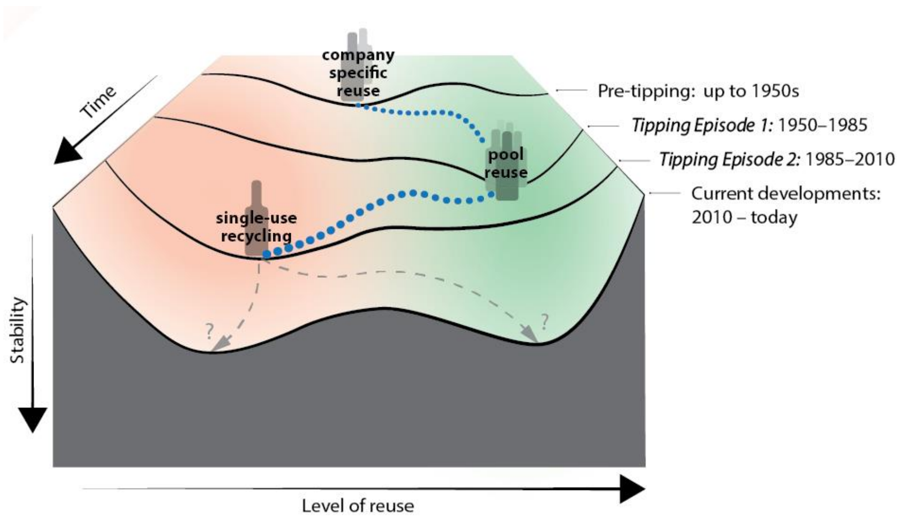


Figure 3: Illustrative visualisation of the development of bottle management systems using the tipping points state-space format. It depicts the progression of the case in Germany from individual company reuse to a widespread reuse system to a single-use recycling system, and potential future pathways. The valleys represent alternative stable states of the system, which differ in their level of reuse, and are evolving over time. The bottle icons represent the actual state of the system at a particular time. The dashed line shows the historical trajectory of the system and the dashed arrows the possible trajectories unfolding now and into the future.

4.2 Tipping episode 1 (1950s – 1985): Tipping from company-specific reuse to pool reuse

In the following we first discuss the enabling conditions. Next, we discuss both the developments that led to the destabilisation of the company-specific reuse systems that existed before the pool bottle, and the enabling feedback loops that allowed for the tipping towards this new state specifically – and we highlight the relevant strategic interventions that triggered the tipping. See also the overview in Fig. 4.

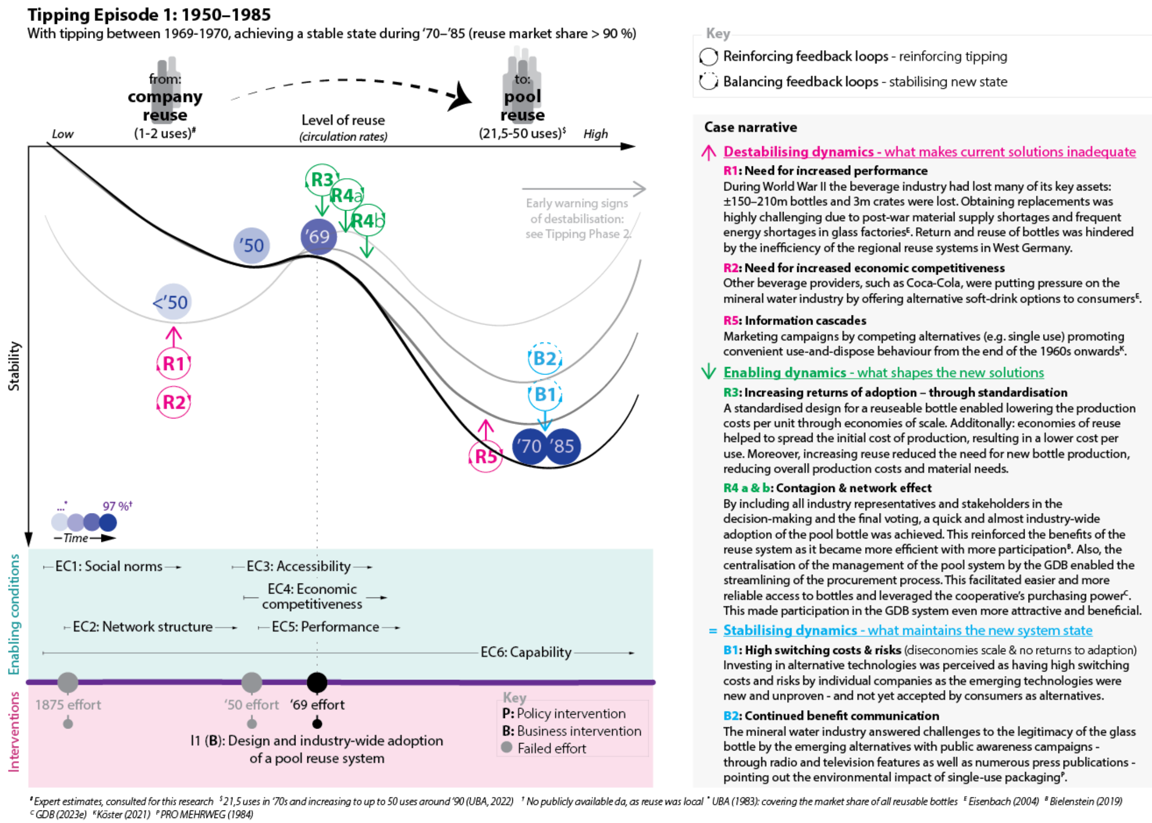


Figure 4: Overview of tipping dynamics in Tipping episode 1.

Enabling conditions: setting the scene for systemic change

Firstly, because of historic reasons bottle reuse was already a common practice, i.e. social norm (EC1) - see above, ensuring the capability (EC6) for reuse behaviour. Second, a special network structure (EC2) emerged - in the form of cooperatives - that allowed tackling shared challenges of the mineral water companies. This was partly driven by the strong regional focus of the companies and partly driven by economic growth. The former limited the competitive overlap in the operating areas (GDB, 2023c) and aided collaboration. The latter, while interrupted by WWII, was rebooted with the economic upswing after the war, and influenced by currency reform and the Marshall Plan. This had the effect that the industry as a whole grew rapidly. Consequently, also the GDB grew: to 133 members by the early 1960s, which represented about three-quarters of West Germany's mineral water companies. All this set the stage for the introduction of the Pearl bottle - see the Intervention (I1(b)) below - whilst the systematised procurement and logistics provided by the GDB made bottle reuse much more accessible (EC3). Moreover, promising lower costs through reducing the need for the production of new bottles contributed to the better economic competitiveness (EC4) of reuse-at-scale in particular. At the same time, advances in manufacturing technologies and more efficient logistics, in the form of more return points in supermarkets as well as the purchasing of replacement bottles and empties exchange by the GDB, meant that the performance (EC5) of reusable bottles - their handling and circulation rate - could now significantly be improved. That is: 6 of 6 enabling conditions of the PTP framework were present (see Fig. 1), although they are interconnected and themselves driven by both global and local enablers.

Tipping: 1969-1970 – Tipping from individual company reuse to pool reuse

The first tipping episode took only a single year: from 1969-1970. After an initial near industry-wide adoption a stable state followed between 1970–1985, where the market share continued to be > 90 %, see Fig. 4.

Destabilising feedback loops: regional reuse no longer fit-for-purpose

In Fig. 4 the destabilising feedback loops are represented by the upwards pushing feedback loops (R1 and R2 – in magenta) indicating the two main reasons that made the company-specific reuse system less fit-for-purpose. First, approximately 150–210 million bottles and 3 million crates were lost during World War II. Obtaining replacements was highly challenging due to post-war material supply shortages as well as frequent energy shortages in glass factories (Eisenbach, 2004). As bottles are an essential asset there was an economic necessity to ensure the return and reusability of bottles. However, this was hindered by the inefficiency – e.g. the low circulation rate and costly sorting and exchange – of the regional reuse systems. As such there was a need for increased performance (R1). In the meantime, also, global soft-drink brands such as Coca-Cola, had successfully entered the beverage market as strong competitors, and the mineral companies recognised this (Eisenbach, 2004) – need for improved economic competitiveness (R2). As a result of these two developments there was a need to stand together and the GDB was formed.

Enabling feedbacks: actions to trigger tipping towards pool-reuse - the (in)active role of policy & business

In Fig. 4 the enabling feedback loops that generate the next 'valley,' representing the next system state that is to follow, are indicated by the downwards pushing reinforcing feedback loops (R3-R4 – in green). In our case, the main triggering Intervention (I1) was the introduction of the Pearl bottle and related services provided by the GDB. The Pearl bottle was to provide both economies of scale and economies of reuse, thus increasing the returns of adoption (R3) of the system. That is: it used both increases in the scale of production – lowering the per-unit-cost, and at the same time spread the initial cost of production - lowering the cost-per-use. And due to the new network structure (the formation of the GDB) contagion (R4a) enabled a near industry-wide adoption (Bielenstein, 2019), further reinforcing benefits gained from increasing returns of adoption (R3).

Here, the role of the enabling conditions can be clearly recognised. Previously, in 1950 the GDB had commissioned the development of a uniform bottle shape, resulting in a standardised design guideline for a bottle with a lever cap. However, this remained a niche experimentation and was not widely adopted: the bottles still needed to be closed manually and were therefore unsuitable for machine handling. Additionally, the breakage rate of the caps and bottles was still high (Eisenbach, 2004). Approximately two decades later, however, due to technological advances, bottles with external screw caps were possible with significantly lower costs (EC4 & EC5). This led to the investment of cooperative GDB and trade association VDM to together develop a new standardised bottle in 1969.

A wide range of actors was involved in this effort, including designers, market researchers, experts for glass works, and representatives of the mineral water companies and cooperatives. The outlook of the actors was to create a system that would serve them long-term, or what would now be called product-system design or whole systems design. That is: the focus was not only on the bottle, but also on creating a well-organised mechanism for the return and refill process through the GDB (Bielenstein, 2019). A relatively quick iterative process (a mere 5 months) was used to optimise both technical and aesthetic requirements - so that the bottle would be lighter and more elegant and modern looking, as suggested in several market research feedback cycles. This resulted in the final Pearl bottle design (see insert Fig. 1) (Bielenstein, 2019). The complementary technological development of stackable and palletized crates (which can be reused over 100 times) also played a pivotal role in enabling smooth logistics for a more efficient performance (EC5) of the system (Eisenbach, 2004).

After the design of the bottle was finalised a vote followed - where, again, a wide range of stakeholders was included - and a decision made with unity led to a quick and almost industry-wide adoption of the pool bottle. Previously, during the 1875 effort, there was no one to take responsibility and leadership of a pool system, but now - with the GDB - this was no longer a barrier. Moreover, the network effect - contagion (R4b) reinforced the functioning of the reuse system as it became more efficient the more companies participated (Bielenstein, 2019) thus further increasing its performance (EC5). Additionally, the central responsibility and management of the pool system by the GDB enabled the streamlining of the bottle procurement process. This facilitated easier and more reliable access (EC5) to the necessary bottles as well as favourable pricing agreements, that were leveraged by the cooperative's purchasing power (GDB, 2023b). This made participation in the GDB system even more attractive and beneficial for the mineral water companies, leading to strong social contagion effects: still, to this day, around 95 % of all mineral water companies are members of the GDB (GDB, 2023a).

In sum: there were strong forces that destabilised the company-specific reuse system, as well as strong - but largely unconnected - forces to enable the pool reuse system. Crucially, also, was that the solution (the pool reuse system) leveraged the new enabling conditions (the possibility to make improvements in performance (EC5) and economic competitiveness (EC4)) to address shortcomings of the company specific reuse (e.g. the need for increased performance (R1) and improved economic competitiveness (R2)), whilst leveraging existing practices (e.g. to consumers there was not much change).

After tipping: stabilisation of the pool reuse system

The pool reuse system had adoption rates above 90% up to the '90s, after which adoption slowly started to decline - early signs of the second tipping episode drawing closer. However, two factors contributed to its initial period of stability. One: investing in alternative technologies was perceived as having high switching costs and risks (B1) by individual companies (Eisenbach, 2004). More so, given that consumer acceptance of these alternatives was still low: PET, for example, was yet not accepted as a packaging material for water (Eisenbach, 2004). But efforts were underway to change this: the single-use tin and aluminium can industry (at the time greater competition to reusable glass than single-use plastics) initiated campaigns that endorsed convenient use-and-dispose behaviour from the late '60s onwards (Köster, 2021) (Information cascades – R5).

Therefore, and second, to reinforce glass as the material of choice, the industry therefore wielded its joint communication power to continue to emphasise the benefits of the system (B2). Already before the tipping, the industry actively shaped the perception of the high quality of natural mineral water compared to table water (Eisenbach, 2004). So when other alternatives emerged the industry responded with initiatives like the PRO MEHRWEG (in English: pro reuse) campaigns – through radio and television features as well as numerous press publications - public awareness around the environmental impact of single-use packaging was raised (PRO MEHRWEG, 1984). This continued effort ensured that reuse was seen in a positive light - reinforcing the social norm of reuse (EC1) and contributed to the preservation of the capability (EC6) of consumers to make an environmentally beneficial choice.

All the developments during the first tipping episode solely include businesses, and no (additional) policy interventions were involved, which was about to change during the second tipping episode.

4.3. Tipping episode 2: 1985 – 2010s: Tipping dynamics away from the reuse regime

Here we follow the structure of the previous section: we discuss the enabling conditions and then the developments that led to the destabilisation of the pool-reuse system, which are also the enabling conditions for the single use system. Next follow the enabling feedback loops that allowed for the tipping towards the currently dominant single-use recycling system - and we highlight the relevant interventions from both business and policy. See Fig. 5, where we depict the change as a reversal to indicate a change that is deemed undesirable from a sustainability perspective.

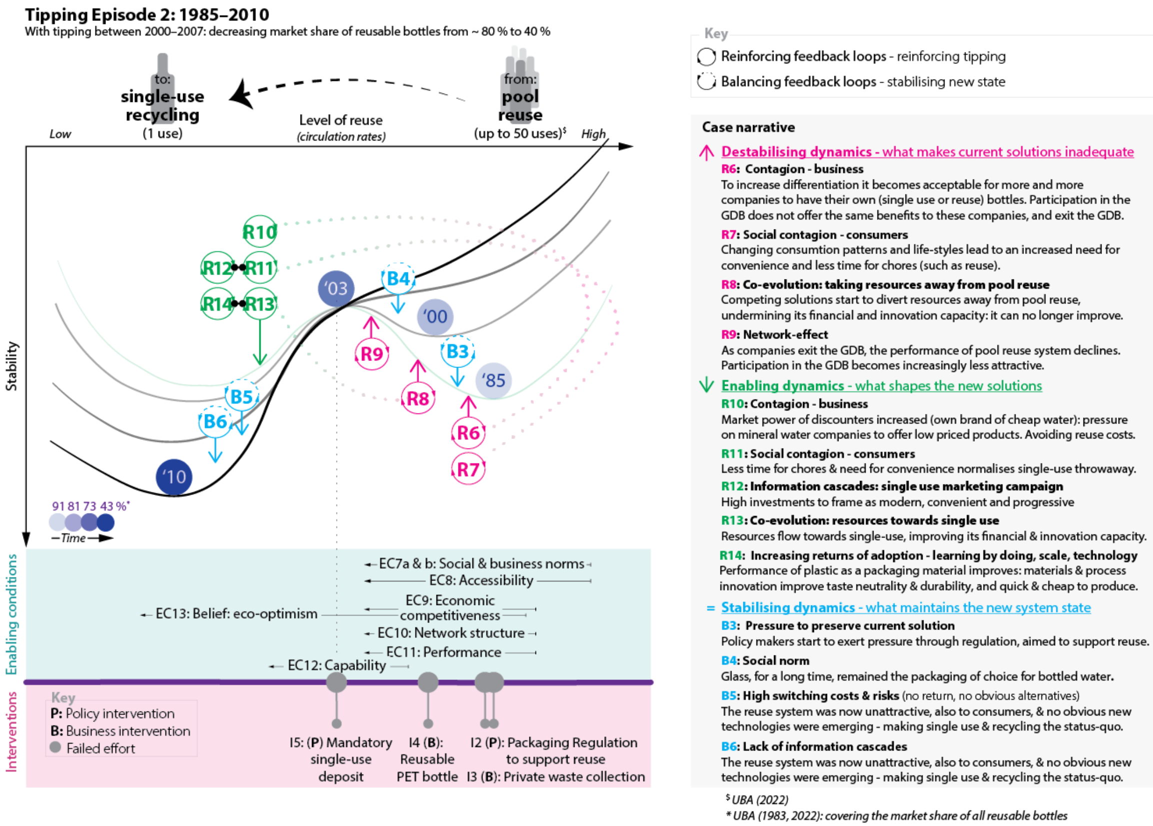


Figure 5: Overview of tipping dynamics in Tipping episode 2.

Enabling conditions[4]: setting the scene for systemic change – yet again

Some of these developments already start in the background of the previous tipping episode, but during this period their influence becomes so pronounced as to decrease the fitness of the pool-bottle reuse system as a solution. For one, post-World War II landscape changes social norms (EC7a). The economic boom, fueled by liberal policies, shifted spending towards convenience and individuality as product choices grew (Fabian, 2021; Köster, 2021), which increased the demand for disposable products. This sparked a related change in business norms (EC7b): with market saturation came fierce competition for customer loyalty (Köhler, 2021). It became important for businesses to pursue tailored marketing strategies and personalised products (Beyering, 1987; Fabian, 2021), challenging the legitimacy of standardised packaging. Additionally, the retail landscape diversified with large chain stores and discounters based on the self-service principle (Köster, 2021), which offered lower prices by simplifying store layouts and selling their own brands. This pressured traditional retailers to adjust pricing strategies.

At the same time, advancements in plastic manufacturing technology significantly reduced production costs with promising economies of scale, leading companies to invest in this new technology. This meant that single-use packaging was not only becoming more available and accessible (EC8): it was also swiftly becoming a cost-effective alternative, thus challenging the economic competitiveness (EC9) of reusable packaging. Moreover: the single-use system did not need a supporting network structure (EC10) in the same manner that the pool reuse required, thus reducing the need for participation in the GDB and the benefits it offered, thus reducing the accessibility (EC8) of the pool reuse system. Shifting investments also had the effect that the financial and innovative capacity of reuse pools declined, making it difficult for the reuse system to keep up with the performance (EC11) of the single-use system: not only was single use becoming cheaper for companies, it was also more convenient for both consumers and companies, and offered more possibilities for differentiation.

And: although the resulting waste from single-use was seen as a problem and recognised by policy makers as such, the complexity of waste management and recycling systems made them difficult to understand for consumers. This made it difficult to know what constituted environmentally friendly behaviour, thus reducing the capability (EC12) of consumers to make informed decisions about this. Moreover, there was a belief - among consumers and policy makers alike - that the newly emerged recycling technologies would be able to solve many of the waste issues, establishing a new norm - belief in eco-optimism (EC13) (Köster, 2021). In short: during this period many of the forces that had previously enabled the tipping towards pool-bottle reuse now reversed direction or stopped being relevant and the door was now open to single-use.

[4] Here, we continue to use 'enabling conditions' as a technical term to mean the conditions that set the scene for tipping towards the single-use recycling system: irrespective of the desirability of the direction or nature of the change.

Tipping: 1985-2000 - Tipping from pool reuse to single use & recycling

The second tipping episode took place over 7 years: from 2000 to 2007. During this period, after already having declined somewhat from its success days of over 90% to > 80 %, the reuse levels declined further to levels around 40% and stayed there between '10-'20. This to the benefit of single use and recycling. Tipping Episode 2 differs from Tipping Episode 1 in one important aspect: the presence of forces that both destabilised the pool system and simultaneously enabled the single-use system. We will first describe the destabilising aspects, before linking them to the enabling feedbacks in the following section. In Fig. 5 these linkages are indicated by the dotted lines connecting the destabilising dynamics on the right with their respective enabling dynamics on the left.

Destabilising feedbacks: competing solutions start to undermine pool-reuse

In Fig. 5 the destabilising feedback loops are depicted by the upwards pushing feedback loops (R6 to R9). These feedbacks are the result of competing solutions undermining the pool reuse system. That is: the general increased competition for market share and the resulting need for product differentiation (EC7 & EC9) affected the packaging for mineral water in particular because the product has inherent limited marketing options. To stand out, distinctive packaging designs became the focus: either serving a low-price market or aiming for a luxurious and modern look for settings like restaurants. Companies responded to this in one of two ways: to either revive earlier company-specific reuse solutions and/ or to develop single-use bottles.

These two developments had the combined effect that the pool system as a whole became less efficient (Lippert et al., 2012): the pool reuse system started to struggle with rising transportation costs, increasing losses and costs for replacement bottles due to lower return rates, and higher costs due to high storage space and staff costs for handling empties (compared to single-use) (UBA, 2010). This started to be problematic due to EC6-10, and favoured the new solutions even more. Being a member of and participating in the GDB bottle reuse system was not needed any longer – and therefore companies exited the GDB and its pool system (UBA, 2010). Pool membership became less appealing: it was acceptable for a business to have its own solution (Contagion – business – R6), and this further compounded the shortcomings of the pool system (Network effect – R9). At the same time the emergence of these competing solutions, and the redirected investments towards single-use this entailed, undermined the financial and innovative capacity of pool reuse (Co-evolution – R8).

As reuse rates declined (see Fig. 1), something needed to change. To preserve the reuse system policy makers issued an ultimatum to the industry: if reuse rates were to drop below 72%, a mandatory deposit would be introduced on single-use packaging (B3). The aim of this was to make single-use more expensive: thereby tilting the playing field towards reuse. To this end, a conditional law was included in the Packaging Regulation[i] that was passed in '91 – Intervention (I2(P)). However, several studies had already predicted it would fail (Sprenger, 1997; Golding, 1999; Baum et al., 2000; UBA, 2010; Hoffmann, 2011): amongst other reasons the mandatory deposit-refund system was likely to lead to "windfall profits" for participating companies due to unreturned bottle deposits and the fact that single-use bottle collection would be exempt from the general EPR[ii] scheme for all packaging (Peters and Czymmek, 2002; BMU and BMWi, 2002). Still, the deposit was adhered to, although the result was characterised as an “obligatory consensus” rather than a “joint agreement” (Hoffmann, 2011: 144). Then, in ‘99, the reuse market share had fallen below 72%[iii], which put the conditional mandate into effect if the market share was breached again in the subsequent one-year review period. Eventually the mandatory deposit was introduced in 2003 – I5(P). But: instead of reversing the downward trend[iv], it – as predicted – provided an advantage to single-use (Jungbauer, 2000; Sachse, 1998): see more in the following section.

This policy failure can be dedicated to a lack of leadership to correct course and steer towards a better solution (Hoffmann, 2011). A subsequent government inherited the Packaging Regulation (policy legacy) and, with reuse rates still falling, was now faced with having to enforce the conditional law that would introduce the mandatory deposit. As a way of reducing the time pressure somewhat, though, the industry was given the opportunity to find their own solution. But, given the lack of political consensus, industry did not make use of this opportunity - but rather waited. As a consequence of industry not taking the political pressure seriously and policy makers needing to show decisive action, an alternative could neither be efficiently designed by its proponents, nor fully prevented by the opponents. Ultimately this led to a ‘solution’ that was not desired by anyone involved (Hoffmann, 2011).

A business intervention was similarly unsuccessful: efforts were made to adjust to the new PET bottle material: a leading mineral water company introduced individual reusable PET bottles in 1998 (Lippert et al., 2012), followed by the GDB cooperative's reusable pool PET bottle and matching crate in 1999 (Eisenbach, 2004) (Intervention - I4(B): Reusable PET). Though these bottles, with an average circulation rate of 25 times and lighter weight, are considered a good eco-efficient packaging option (UBA, 2016), surpassing reusable glass bottles, they couldn't prevent the rise of single-use bottles.

Simultaneously, the increasing need for convenience, driven by factors like rising employment, smaller households, an ageing population, increased out-of-home consumption, and decreasing time for chores (such as returning bottles) (Fabian, 2021) resulted in a decline in reuse practices (Social contagion – consumers – R7). Even though, for a long time, glass was considered the material of choice (B4), this balancing loop was insufficient to preserve the glass reuse pool system.

As destabilising feedbacks undermine the pool reuse system and interventions aimed at preserving it instead stimulate single use ‘tipping’ towards this seems inevitable.

Enabling feedbacks: towards single-use

A number of the previous feedback loops not only destabilised the pool reuse system, but also – at the same time – enabled single use. Such a strong linkage is seen, for example, for R10 contagion – business which formed a dual force with R6 contagion - business. That is: the aggressive low-price strategies employed by discount stores for mineral water (UBA, 2010), forced mineral water companies to adapt. Discounters deliberately used cheap mineral water in single-use bottles to create customer loyalty, avoiding the costs of reusable bottle infrastructure. Their market power and refusal to participate in the reuse system weakened its effectiveness. The dominance of discounters led the mineral water companies to also adopt single-use packaging for low-priced channels (Stracke and Homann, 2017; UBA, 2010). As such, R6 describes the decline of the reuse pool, whilst R10 emphasises the rise of single-use as a result of the same developments.

Similarly, social contagion – consumers (R7) on diminishing reuse practices has as its counterpart social contagion – consumers (R11) on normalising single use. That is: the increasing need for convenience has the direct effect of both destabilising reuse and enabling single-use and throw-away practices. That is: single-use is the automatic and only logical alternative to the cleaning, sorting, storing and returning of bottles. This is further reinforced by Information cascades (R12), where – following the significant investments in transitioning to single-use bottle production – companies heavily invested in marketing single-use bottles as modern, convenient, and progressive (Lippert, 2012), reinforcing their appeal.

R8 and R13 involving co-evolution are mirrored in much the same way: because finite resources are being rerouted towards (a.o.) single-use, these are not available for (continuing to) improve the pool reuse system. This also sets in motion increasing returns of adoption (R14) for single use, as this system improves: driven by technological improvements in plastic bottles, including enhanced taste neutrality, durability, and functionality (Eisenbach, 2004). These advancements, combined with economies of scale from quick and inexpensive mass production, reinforced the widespread adoption of plastic bottles.

A key intervention, in triggering tipping – as discussed in the previous section – was the introduction of the mandatory deposit – Intervention (I5(P)): after 2003, when it was first introduced, the reuse market share continued to decline sharply whilst single use rose equally quick. Much of this can be attributed to the way in which the scheme was designed. For example: the recently introduced EPR scheme – which made companies responsible for their waste – had as its underpinning assumption that the bottle reuse system could be preserved as well as recycling stimulated. An important factor in this was the promise of and trust in the new recycling technologies – see (EC13). But where the EPR scheme applied to packaging in general, only bottles were singled out for reuse. And as already anticipated by experts at the time, since the recycling infrastructure did not incorporate reuse infrastructure, this favoured the single-use regime in general, making the reuse option for bottles unattractive.

And also: the mandate required retailers to accept returns of all deposited single-use bottles, but this did not apply to reusable bottles. What's more: technologies like vending machines improved the efficiency of the single-use system but didn't accommodate reusables at that time. Additionally, the higher deposit for single-use bottles (25 ct) compared to reusables (8–15 ct) provided consumers with stronger incentives to choose single-use, contrary to the intended goal of making it less attractive (UBA, 2010). Single use was thus both a simpler option for producers as well as more convenient and more worthwhile financially for consumers, whilst also appearing as the most modern (EC7a).

In sum: the dual forces of R7–R11, R6–R10 and R8–R13 conspire to undermine pool reuse and simultaneously enable single-use, whilst the intervention – which intended to preserve reuse – inadvertently triggered tipping to single-use.

After tipping: stabilisation of the single-use system

The introduction of Germany's mandatory deposit system for single-use bottles had created three parallel collection systems: the household Dual System for recycling (for all packaging waste), the mandatory deposit-return system for single-use bottles, and the voluntary deposit-return system for reusables. This complexity led to confusion and frustration among consumers and businesses, making it difficult to navigate the various processes and understand the differences between single-use and reusable options. The varying deposit amounts and lack of clear information on environmental impacts further compounded the issue, giving consumers the false impression that all collection methods were equally environmentally friendly, which further stabilised the new regime (a lack of informational cascades – B5) (UBA, 2010). Moreover, similar to the previous tipping episode, as considerable efforts and investments had been spent, changing it back or finding yet another solution was associated with high switching costs and risks (B6) for individual companies.

4.4 2010s–today: current developments and looking ahead - continued interaction of reuse and recycling

The market share for reusable bottles seems to have stabilised at around 40 % from 2010 till 2020. In the meantime, the GDB has responded to current trends by introducing additional bottle sizes and designs. Currently more than 70 % of all reusable bottles are GDB pool bottles (glass and PET) (GDB, 2023a), the rest are individual reusable bottles. Many established mineral water companies and retailers offer water in several packaging types, aiming at different consumer segments, while most discounters still exclusively offer single-use packaging. However, while LIDL relies on the alleged eco-efficiency of the bottle-to-bottle recycling system (Kolf, 2023), ALDI recently announced it would restart testing a reusable bottle system from 2024 in light of the strongly increasing political interest in promoting circular strategies (Bender, 2023).

With the increasing pressure exerted by policy makers to create a more circular economy (with ambitious targets for both reuse and recycling) and to do so swiftly, the question of how to bring about this change away from the linear economy and with interacting circular strategies – within the domain of packaging and elsewhere – is still highly relevant today. That is: how to effectively design a circular configuration – a situation where two or more circular strategies interact (Blomsma and Brennan, 2017; Blomsma et al., 2023) – so that both business and environmental benefits are optimised? In the next section, we derive insights and guidance from this historical case for both academics aiming to understand and support the transition towards a circular economy and the change agents within policy and business involved in it.

5 Discussion

The unfolding of the two tipping episodes could be interrogated in an insightful manner through applying the PTP framework. It has allowed for identifying what enabling conditions had emerged, how this problematized current solutions, and what interventions set in motion which feedback loops. Fig. 4 and 5 show how applying PTP allows for drawing out the richness in dynamics that played a role. and the importance of new solutions leveraging feedback loops to become established quickly. Alongside showing the analytical value of the PTP framework, the case illustrated other change dynamics that are in line with established knowledge about decline and destabilisation, such as, for example, repurposing of existing elements (reframing the reuse behaviour consumers already exhibited in Tipping Episode 1) or that there may be a period of confusion and contention (the competing solutions in Tipping Episode 2).

Destabilising & enabling feedback loops

However, through distinguishing between both destabilising and enabling feedback loops, additional insights could be identified as the episodes differ in how these loops interact. That is: in Episode 2 (part of) what destabilised the current system (pool reuse) at the same time enabled the new system to emerge (single use combined with recycling). This (strong) dual-force effect was not seen in Episode 1. The linking of destabilising and enabling dynamics implies that this dynamic may be a factor to consider in tipping. That is: in Episode 1 there was no pre-existing central solution, the circular strategy was only different in its execution (from company specific reuse to pool reuse) and relied largely on different practices within business within the sector (thus limited in number of actors involved). As such, there was only limited destabilisation of the pre-existing solution needed. This was not so for Episode 2: there was a pre-existing central solution, the change was to a different circular strategy (recycling), and the change involved packaging in general as well as consumers. Therefore, how to 'make space for the new' seems an important phenomenon to pay attention to in tipping, and the nature of the pre-existing system as well as the nature of the proposed change are a factor in path-dependency. But how, exactly, this can or should happen - dismantling, repurposing, exaptation, etc – with regards to sustainable transitions requires further work.

Worth noting in this regard, also, was the fact that in Episode 2 the possibility to circumvent the GDB pool system – the possibility to not be part of the existing network structure – started to undermine and weaken it. That is: where the network was an enabling condition in Episode 1 – here non-participation started to become an advantage. In this sense, the reversal of the enabling conditions could also in and of themselves be enabling conditions.

Possible fruitful avenues to further investigate these phenomena could be linking and extending the PTP framework with work, for example, on path dependency (Arthur, 2008; Mahoney and Thelen, 2010) and the Theory of the Adjacent Possible (Kauffman, 2000, 1996). Moreover, and specific to a circular economy, there is scope to design (economic) experiments to examine the conditions controlling the tipping between reuse and recycling systems. Approaches based on existing experimental economics studies on tipping into or out of coordination and tipping of social norms (Barrett and Dannenberg, 2014) could serve as examples. That is: experiments where a large number of groups 'play the game' under different conditions in order to build up statistical learning that is then used for modelling. 'Natural experiments', such as taking place in the Netherlands and Germany at the moment – where attempts are being made to reintroduce reuse as well as improve recycling rates - could also be used to gain insight into relevant dynamics and to inform the further roll-out of similar interventions in other countries.

Wicked solutions: leadership, ownership and actor-networks

Another key takeaway from the bottle-reuse case is that the solution introduced in Episode 2 is not desired by those involved. Although it is difficult to speculate what would have been the 'best' solution, it is clear that – compared to Episode 1 – Episode 2 shows failure when it comes to leadership and ownership of the solution. In Episode 1 the GDB – in which its members also hold an ownership stake – has a key role in bringing together stakeholders in the design phase as well as managing the resulting pool reuse system. Compare this to Episode 2, where a simplistic view involving wishful thinking of policy makers when it comes to the impact of the Packaging Regulation and a wait-and-see approach by both business and policy result in a wicked solution (Rittel and Webber, 1973). What this points to is that PTP could benefit from more insight into the political economy – e.g. lobbying, formation of interest groups, etc – as these dynamics are not currently explicitly included in the framework. One fruitful avenue is to further explore social tipping points (Smith et al., 2020), as well as linkages with other work on cross-sectoral collaboration (Dentoni et al., 2021; Stadtler et al., 2024). (Elements of) game theory and agent-based modelling can also be included as part of the method, respectively, to think through the responses of various actors and understand how the behaviour of the system as a whole is influenced by this.

Balancing loops and why slower can be faster

A last take away is the influence of balancing loops post-tipping that we observed in the two tipping episodes. These are important in two ways. First, if tipping results in a system that is undesirable, there is a certain lock-in effect as resources have been spent (finance, attention, motivation, etc) – and the new solution is likely to be stable for at least some time – as both Tipping Episodes were. This is an important argument for proceeding with caution. In fact, it may be why 'slower = faster': to not pursue speed for the sake of speed, which risks losing momentum.

Second, when the change is indeed desirable, there may be a need for maintenance or after-care to stabilise the new system. That is: to not become complacent and take the solution for granted. Whilst in Episode 1 these efforts eventually were not sufficient to stop the second tipping episode, it may have delayed its onset. This does not necessarily mean that the solutions need to be rigidly adhered to: but as with the pool reuse system in Episode 2, it requires continuous improvement to keep-up its fitness, otherwise it will deteriorate - and to ensure this is resourced independently of other developments. That is: how can maintaining balancing loops be made resilient? One fruitful avenue to gain further insight into this could be to explore additional cases of balancing dynamics and how these lessons could be used to extend the PTP framework.

PTP as a method for designing interventions

Working with the PTP framework and the insights it generated have led us to compose a process model of PTP, describing the steps and the key questions that need to be answered when using PTP as a method to develop solutions and innovations for current problems. That is: how to use PTP as a method – see Fig. 6. As well as extending it with steps at the beginning and end to form a process, the centre contains an iterative loop, where the interventions and the reinforcing feedback loops are considered in turn, whilst key questions are answered along the way. In this manner the PTP framework facilitates a focus on the dynamics and interaction of various forces – and enables those using the framework to consider different scenarios and interactions. The key questions, based on this current work, force a critical perspective on the proposed solutions – and to test the viability and robustness of proposed solutions.

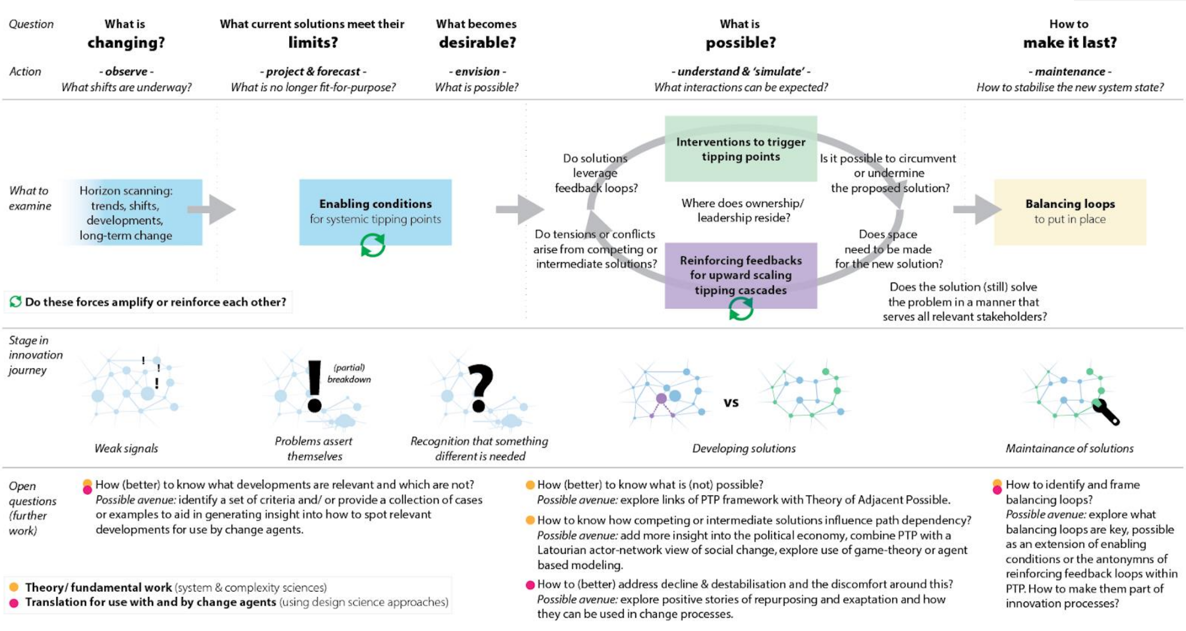


Figure 6: An overview of PTP-as-a-method: what steps need to be taken and what key questions need to be answered in order to gain insight into what interventions may bring about tipping for use in analysing current problems and designing suitable solutions.

6 Conclusion

Through a historical case study – consisting of two tipping episodes examined through the Positive Tipping Points (PTP) framework (Lenton et al, 2022) – we gained insight into the dynamics of tipping, and in particular on how destabilising and enabling feedback loops are related. That is: if the proposed change involves a pre-existing central solution, a qualitatively different solution, and a large number of actors, destabilisation may be an integral part of tipping. As such, there is a need for interventions that both steer towards what is desired, and away from what is not wanted simultaneously, whilst considering how different solutions may influence each other.

In this light Buckminster-Fuller's famous quote "You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete" whilst it may have been true in his time, it now has to be adapted to say: "To change something, you have to fight the existing reality, whilst also building a new model that makes the existing model obsolete”. For a circular economy this means that it needs to be understood how the linear economy can be outcompeted as well as how different circular strategies may interact. Whilst these are not necessarily new insights separately, this study shows the relevance of both simultaneously.

A key implication of the insights on destabilisation and wicked solutions - for both knowledge creation and impact driven work - is that whole system or systemic design is needed, combined with a human-centred perspective on change and change management. Solutions cannot be designed in isolation, without considering both what is being replaced and the dynamic that competing and intermediate solutions bring to the table - and what competing and conflicting interests are involved. In this sense, our work offers support for the emergent domain of translational systems sciences (Springer, 2024), specifically systemic design (Jones and Kijima, 2018; Jones and van Ael, 2023), which seeks to understand and influence complex, interconnected systems by considering all their components, relationships, and potential futures by combining holistic, interdisciplinary approaches with creative design thinking and rigorous systems analysis. Our study provides an example of how design science approaches can be used for further developing PTPs: through a case study insights were derived that are then codified in a first version of a prescriptive tool and method. These are the first steps in design science approaches, such as Design Research Methodology (DRM) (Blessing and Chakrabarti, 2009) or echeloned Design Science Research (eDSR) (Tuunanen et al., 2024), where insights are translated into a prescriptive framework or method, which are then further refined through additional cases and field-work. We encourage and welcome such further work.

Author contributions. FB and MO designed the study, conducted the research and wrote the paper with input from TL. FB and MO prepared the figures with input from TL. TL contributed the theoretical framework and edited the paper.

Competing interests. At least one of the authors is a member of the editorial board of Earth System Dynamics.

Acknowledgements. The authors would like to thank Tobias Bielenstein for an insightful interview and Dr. Uwe Spiekermann and Dr. Stefanie van de Kerkof for helpful advice on economic history research.

References

References

Abson, D. J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., Wehrden, H. von, Abernethy, P., Ives, C. D., Jager, N. W., and Lang, D. J.: Leverage points for sustainability transformation, Ambio, 46, 30–39, https://doi.org/10.1007/s13280-016-0800-y, available at: https://link.springer.com/article/10.1007/s13280-016-0800-y, 2017.

Antikainen, M., Aminoff, A., Paloheimo, H., and Kettunen, O.: Designing circular business model experimentation - Case study, ISPIM Innovation Forum, 2017.

Arthur, W. B.: Increasing returns and path dependence in the economy, 8th printing, Economics, cognition and society, University of Michigan Press, Ann Arbor, 201 pp., 2008.

Barrett, S. and Dannenberg, A.: Sensitivity of collective action to uncertainty about climate tipping points, Nature Clim Change, 4, 36–39, https://doi.org/10.1038/nclimate2059, available at: https://www.nature.com/articles/nclimate2059, 2014.

Baum, H.-G., Cantner, J., and Michaelis, P.: Pfandpflicht für Einweggetränkeverpackungen?, Augsburg, 2000.

Bender, H.: Getränkesortiment: Aldi Süd will Mehrweg testen, Lebensmittel Zeitung, 21.06.2023, available at: https://www.lebensmittelzeitung.net/handel/nachrichten/getraenkesortiment-aldi-sued-will-mehrweg-testen-171898, last access: 4 October 2023, 2023.

Bergek, A., Hellsmark, H., and Karltorp, K.: Directionality challenges for transformative innovation policy: lessons from implementing climate goals in the process industry, Industry and Innovation, 30, 1110–1139, https://doi.org/10.1080/13662716.2022.2163882, 2023.

Beyering, L.: Individual Marketing: Wege zum neuen Konsumenten, Verlag Moderne Industrie, Landsberg am Lech, 199 pp., 1987.

Bielenstein, T.: Seit 50 Jahren klar, was drin ist: Sonderheft 50 Jahre Perlenflasche, 14 pp., 2019.

Bjerkan, K. Y., Nørbech, T. E., and Nordtømme, M. E.: Incentives for promoting Battery Electric Vehicle (BEV) adoption in Norway, Transportation Research Part D: Transport and Environment, 43, 169–180, https://doi.org/10.1016/j.trd.2015.12.002, available at: https://www.sciencedirect.com/science/article/pii/S1361920915002126, 2016.

Blessing, L. T. and Chakrabarti, A.: DRM, a Design Research Methodology, Springer London, London, 2009.

Blomsma, F. and Brennan, G.: The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity, Journal of Industrial Ecology, 21, 603–614, https://doi.org/10.1111/jiec.12603, 2017.

Blomsma, F., Tennant, M., and Ozaki, R.: Making sense of circular economy: Understanding the progression from idea to action, Bus Strat Env, 32, 1059–1084, https://doi.org/10.1002/bse.3107, available at: https://onlinelibrary.wiley.com/doi/pdfdirect/10.1002/bse.3107?download=true, 2023.

Blomsma, F., Bauwens, T., Weissbrod, I., and Kirchherr, J.: The ‘need for speed’: Towards circular disruption—What it is, how to make it happen and how to know it's happening, Business Strategy and the Environment, 1–22, https://doi.org/10.1002/bse.3106, 2022.

BMU and BMWi: Bericht an das Bundeskanzleramt – Schätzungen der Kosten bei Einführung eines Pflichtpfandes auf Einweggetränkeverpackungen, Berlin, 2002.

Bünemann, A., Rachut, G., Christiani, J., Langen, M., and Wolters, J.: Planspiel zur Fortentwicklung der Verpackungsverordnung: Teilvorhaben 1: Bestimmung der Idealzusammensetzung der Wertstofftonne, 192 pp., 2011.

Chandy, R. K. and Tellis, G. J.: The Incumbent's Curse? Incumbency, Size, and Radical Product Innovation, Journal of Marketing, 64, 1–17, https://doi.org/10.1509/jmkg.64.3.1.18033, 2000.

Christinsen, C. M.: Exploring the limits of the technology s-curve.: Part II: Architectural technologies, Production and Operations Management, 1, 358–366, https://doi.org/10.1111/j.1937-5956.1992.tb00002.x, 1992.

Coelho, P. M., Corona, B., and Worrell, E.: Reusable vs single-use packaging: A review of environmental impacts, 81 pp., 2020.

Dakos, V., Carpenter, S. R., van Nes, E. H., and Scheffer, M.: Resilience indicators: prospects and limitations for early warnings of regime shifts, Phil. Trans. R. Soc. B, 370, 20130263, https://doi.org/10.1098/rstb.2013.0263, 2015.

Denton, C. and Weber, H.: Rethinking waste within business history: A transnational perspective on waste recycling in World War II, Business History, 64, 855–881, 2022.

Dentoni, D., Pinkse, J., and Lubberink, R.: Linking Sustainable Business Models to Socio-Ecological Resilience Through Cross-Sector Partnerships: A Complex Adaptive Systems View, Business & Society, 60, 1216–1252, https://doi.org/10.1177/0007650320935015, 2021.

DUH: Informationen zum umweltfreundlichen deutschen Mehrwegsystem: Hintergrundpapier, Deutsche Umwelthilfe, 16 pp., 2014a.

DUH: Stellungnahme der „Mehrweg-Allianz“ zur Studie „Umlaufzahlen und Transportentfernungen in der Getränkeindustrie“ der Bundesvereinigung der Deutschen Ernährungsindustrie e.V. (BVE) und des Handelsverbands Deutschland e.V. (HDE), 2014b.

Eisenbach, U.: Mineralwasser: Vom Ursprung rein bis heute; Kultur- und Wirtschaftsgeschichte der deutschen Mineralbrunnen; VDM Verband Deutscher Mineralbrunnen e.V. 100 Jahre, Verband Dt. Mineralbrunnen, Bonn, 326 pp., 2004.

EMF: Unlocking a reuse revolution: scaling returnable packaging, 2023.

Eunomia: Assessing Climate Impact: Reusable Systems vs. Single-use Takeaway Packaging, 25 pp., 2023.

European Commission: Proposal for a regulation of the European Parliament and of the council on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC: PPWR, 118 pp., 2022.

European Commission: A new Circular Economy Action Plan: For a cleaner and more competitive Europe, 20 pp., 2020.

Fabian, S.: Individualisierung, Pluralisierung und Massenkonsum: Wandel von Konsummustern im 20. Jahrhundert, in: Konsum im 19. und 20. Jahrhundert, edited by: Kleinschmidt, C. and Logemann, J., De Gruyter Oldenbourg, Berlin, Boston, 337–362, 2021.

Fesenfeld, L. P., Schmid, N., Finger, R., Mathys, A., and Schmidt, T. S.: The politics of enabling tipping points for sustainable development, One Earth, 5, 1100–1108, https://doi.org/10.1016/j.oneear.2022.09.004, 2022.

Fischer, L.-B. and Newig, J.: Importance of Actors and Agency in Sustainability Transitions: A Systematic Exploration of the Literature, Sustainability, 8, 476, https://doi.org/10.3390/su8050476, available at: https://www.mdpi.com/2071-1050/8/5/476, 2016.

Foamie: About our products, https://www.foamie.com/pages/about-our-products, last access: 22 September 2024, 2024.

FOLU and GSI: Positive Tipping Points for Food and Land Use Systems Transformation, 1–73, available at: https://www.foodandlandusecoalition.org/wp-content/uploads/2021/07/Positive-Tipping-Points-for-Food-and-Land-Use-Systems-Transformation.pdf, 2021.

Foster, R. N.: Innovation, Gabler Verlag Wiesbaden, 1986.

GDB: Daten, https://www.gdb.de/mehrweg/daten/, last access: 7 October 2023, 2023a.

GDB: Poolmanagement, https://www.gdb.de/gdb/poolmanagement/, last access: 7 October 2023, 2023b.

GDB: Die Genossenschaft, https://www.gdb.de/gdb/die-genossenschaft/, last access: 4 October 2023, 2023c.

Geels, F. W.: The multi-level perspective on sustainability transitions: Responses to seven criticisms, Environmental Innovation and Societal Transitions, 1, 24–40, https://doi.org/10.1016/j.eist.2011.02.002, 2011.

Geels, F. W. and Ayoub, M.: A socio-technical transition perspective on positive tipping points in climate change mitigation: Analysing seven interacting feedback loops in offshore wind and electric vehicles acceleration, Technological Forecasting and Social Change, 193, 1–20, https://doi.org/10.1016/j.techfore.2023.122639, 2023.

Geels, F. W., Sovacool, B. K., Schwanen, T., and Sorrell, S.: Sociotechnical transitions for deep decarbonization, Science (New York, N.Y.), 357, 1242–1244, https://doi.org/10.1126/science.aao3760, available at: https://www.science.org/doi/pdf/10.1126/science.aao3760, 2017.

Gioia, D.: A Systematic Methodology for Doing Qualitative Research, The Journal of Applied Behavioral Science, 57, 20–29, https://doi.org/10.1177/0021886320982715, 2021.

Golding, A.: Gutachterliche Stellungnahme zur Wirksamkeit einer Pfandpflicht auf Einweg- Bier- und Mineralwasser-Verpackungen zur Stabilisierung der Mehrwegquote, Tübingen, 1999.

Grin, J., Rotmans, J., and Schot, J.: Transitions to sustainable development: New directions in the study of long term transformative change, Routledge studies in sustainability transitions, 1, Routledge, New York, NY, 2010.

Gross, R., Hanna, R., Gambhir, A., Heptonstall, P., and Speirs, J.: How long does innovation and commercialisation in the energy sectors take? Historical case studies of the timescale from invention to widespread commercialisation in energy supply and end use technology, 123, 2018.

Gunderson, L. H. and Holling, C. S.: Panarchy: Understanding Transformations in Human and Natural Systems, Biological Conservation, 114, https://doi.org/10.1016/S0006-3207(03)00041-7, available at: https://www.researchgate.net/publication/37717304_Panarchy_Understanding_Transformations_In_Human_And_Natural_Systems, 2002.

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

Hekkert, M. P., Suurs, R., Negro, S. O., Kuhlmann, S., and Smits, R.: Functions of innovation systems: A new approach for analysing technological change, Technological Forecasting and Social Change, 74, 413–432, https://doi.org/10.1016/j.techfore.2006.03.002, 2007.

Hoffmann, R.: „Was lange währt…“ – Die Einführung des Einwegpfands in Deutschland, dms, 4, 107–124, https://doi.org/10.3224/dms.v4i1.05, 2011.

IFEU: Ökobilanz für PET-Einwegsysteme unter Berücksichtigung der Sekundärprodukte: Endbericht, 28 pp., 2004.

Jones, P. and Kijima, K.: Systemic Design, 8, Springer Japan, Tokyo, 2018.

Jones, P. H. and van Ael, K.: Design journeys through complex systems: Practice tools for systemic design, BIS Publishers, Amsterdam, 251 s., 2023.

Jungbauer, W.: Vorsicht Zwangspfand!, Müllmagazin, 2000, 43–45, 2000.

Kandori, M., Mailath, G. J., and Rob, R.: Learning, Mutation, and Long Run Equilibria in Games, Econometrica, 61, 29–56, https://doi.org/10.2307/2951777, 1993.

Kauffman, S. A.: Investigations, OxfordUniversity Press, Oxford, 2000.

Kauffman, S. A.: Investigations: The nature ofautonomous agents and the worlds they mutually create., SFI working paper, 1996.

Kemp, R., Pel, B., Scholl, C., and Boons, F.: Diversifying deep transitions: Accounting for socio-economic directionality, Environmental Innovation and Societal Transitions, 44, 110–124, https://doi.org/10.1016/j.eist.2022.06.002, 2022.

Kleinschmidt, C. and Logemann, J. (Eds.): Konsum im 19. und 20. Jahrhundert, Handbücher zur Wirtschaftsgeschichte, De Gruyter Oldenbourg, Berlin, Boston, 658 pp., 2021.

Köhler, I.: Marketing als Lockmittel des Konsums: Innovationen in Marktforschung und Werbung, in: Konsum im 19. und 20. Jahrhundert, edited by: Kleinschmidt, C. and Logemann, J., De Gruyter Oldenbourg, Berlin, Boston, 459–483, 2021.

Kolf, F.: Discounter: Lidl wehrt sich gegen Einführung einer Mehrwegpflicht, Handelsblatt, 19.04.2023, available at: https://www.handelsblatt.com/unternehmen/handel-konsumgueter/discounter-lidl-wehrt-sich-gegen-einfuehrung-einer-mehrwegpflicht-fuer-getraenkeflaschen-/29098910.html, last access: 4 October 2023, 2023.

Kondratieff, N. D. and Stolper, W. F.: The Long Waves in Economic Life, The Review of Economics and Statistics, 17, 105, https://doi.org/10.2307/1928486, available at: http://www.jstor.org/stable/1928486, 1935.

König, W.: Geschichte der Wegwerfgesellschaft: Die Kehrseite des Konsums, Franz Steiner Verlag, Stuttgart, 1170 pp., 2019.

Kopp, R. E., Shwom, R. L., Wagner, G., and Yuan, J.: Tipping elements and climate–economic shocks: Pathways toward integrated assessment, Earth's Future, 4, 346–372, https://doi.org/10.1002/2016EF000362, 2016.

Köster, R.: Abfall und Konsum, in: Konsum im 19. und 20. Jahrhundert, edited by: Kleinschmidt, C. and Logemann, J., De Gruyter Oldenbourg, Berlin, Boston, 515–536, 2021.

Kuhn, T. S.: The Structure of Scientific Revolutions, 1962.

Lenton, T. M.: Tipping positive change, Philosophical transactions of the Royal Society of London. Series B-Biological sciences, 375, 1–8, https://doi.org/10.1098/rstb.2019.0123, 2020.

Lenton, T. M., Benson, S., Smith, T., Ewer, T., Lanel, V., Petykowsky, E., Powell, T. W. R., Abrams, J. F., Blomsma, F., and Sharpe, S.: Operationalising positive tipping points towards global sustainability, Global Sustainability, 1–16, available at: ila, 2022.

Lenton, T. M., Rockström, J., Gaffney, O., Rahmstorf, S., Richardson, K., Steffen, W., and Schellnhuber, H. J.: Climate tipping points - too risky to bet against, Nature, 575, 592–595, https://doi.org/10.1038/d41586-019-03595-0, available at: https://www.nature.com/articles/d41586-019-03595-0, 2019.

Lippert, N., Schuck, J., and Spona, P.: 125 Jahre: Das Wasser mit Stern, https://issuu.com/gerolsteiner/docs/125-jahre-gerolsteiner?e=7450575/1566347, last access: 4 October 2023, 2012.

Loorbach, D.: Transition management: New mode of governance for sustainable development. Dutch Research Institute for Transitions (DRIFT), Energy Policy, 35, 6060–6074, available at: https://www.researchgate.net/publication/289541010_Transition_management_New_mode_of_governance_for_sustainable_development_Dutch_Research_Institute_for_Transitions_DRIFT, 2007.

Mahoney, J. and Thelen, K. A.: Explaining institutional change: Ambiguity, agency, and power, Cambridge University Press, Cambridge, Madrid, xiii, 236 p, 2010.

Meadows, D. H.: Leverage points: Places to intervene in a system, available at: https://groups.nceas.ucsb.edu/sustainability-science/2010%20weekly-sessions/session-112013-11.22.2010-managing-for-sustainability-speaker-pamela-matson/supplemental-readings-from-the-reader/Meadows.%201999%20Leverage_Points.pdf/at_download/file, 1999.

Meckling, J., Kelsey, N., Biber, E., Zysman, and J.: Winning coalitions for climate policy, Science, 349, 1170–1171, https://doi.org/10.1126/science.aab1336, 2015.

Otto, I. M., Donges, J. F., Cremades, R., Bhowmik, A., Hewitt, R. J., Lucht, W., Rockström, J., Allerberger, F., McCaffrey, M., Doe, S. S. P., Lenferna, A., Morán, N., van Vuuren, D. P., and Schellnhuber, H. J.: Social tipping dynamics for stabilizing Earth's climate by 2050, Proceedings of the National Academy of Sciences of the United States of America, 117, 2354–2365, https://doi.org/10.1073/pnas.1900577117, 2020.

Perez, C.: Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages, Edward Elgar, Cheltenham, 218 pp., 2011.

Peters, M. and Czymmek, F.: Das Zwangspfand auf Einweggetränkeverpackungen – eine ökologisch-ökonomische Analyse: Arbeitsberichte zum Umweltmanagement Nr. 9, Wirtschafts- und Sozialwissenschaftliche Fakultät, Köln, 9, 2002.

PRO MEHRWEG: Getränkeverpackungen: Daten und Fakten 1983/84, PRO MEHRWEG, 1984, 1984.

Quoden: Umweltrecht am Beispiel des Verpackungsbereichs, in: Integratives Umweltmanagement: Systemorientierte Zusammenhänge zwischen Politik, Recht, Management und Technik, edited by: Kramer, M. and Gabriel, S., Gabler, Wiesbaden, 263–276, 2010.

Rittel, H. W. T. and Webber, M. M.: Dilemmas in a General Theory of Planning, Policy Sciences, 155–169, available at: https://www.sympoetic.net/Managing_Complexity/complexity_files/1973%20Rittel%20and%20Webber%20Wicked%20Problems.pdf, 1973.

Rogers, E. M.: Diffusion of innovations, Free Press of Glencoe, New York, 1962.

Rosenbloom, D., Markard, J., Geels, F. W., and Fuenfschilling, L.: Why carbon pricing is not sufficient to mitigate climate change-and how "sustainability transition policy" can help, Proceedings of the National Academy of Sciences of the United States of America, 117, 8664–8668, https://doi.org/10.1073/pnas.2004093117, 2020.

Sachse, K.: Zwangspfand als Bumerang, Fokus, 1998, 1998.

Schot, J. and Geels, F. W.: Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy, Technology Analysis & Strategic Management, 20, 537–554, https://doi.org/10.1080/09537320802292651, 2008.

Schuck, J.: Gerolsteiner Brunnengeschichte, https://issuu.com/gerolsteiner/docs/150331122010-54aea4bb728d4fb88919417c4435c45e/50, last access: 4 October 2023, 2015.

Seifert, D.: Die Geburtsstunde des Grünen Punktes. Die Verpackungsverordnung von 1991 und die Einführung des Dualen Abfallwirtschaftssystems in Deutschland, dms, 4, 87–106, https://doi.org/10.3224/dms.v4i1.04, 2011.

Sharpe, S. and Lenton, T. M.: Upward-scaling tipping cascades to meet climate goals: plausible grounds for hope, Climate Policy, 21, 421–433, https://doi.org/10.1080/14693062.2020.1870097, 2021.

Smith, A., Stirling, A., and Berkhout, F.: The governance of sustainable socio-technical transitions, Research Policy, 34, 1491–1510, https://doi.org/10.1016/j.respol.2005.07.005, available at: https://www.sciencedirect.com/science/article/pii/S0048733305001721, 2005.

Smith, S. R., Christie, I., and Willis, R.: Social tipping intervention strategies for rapid decarbonization need to consider how change happens: Mealy, Proceedings of the National Academy of Sciences of the United States of America, 117, 10629–10630, https://doi.org/10.1073/pnas.2002331117, 2020.

Sovacool, B. K.: How long will it take? Conceptualizing the temporal dynamics of energy transitions, Energy Research & Social Science, 13, 202–215, https://doi.org/10.1016/j.erss.2015.12.020, 2016.

Sprenger, U.: Förderung ökologisch sinnvoller Getränkeverpackungen, ifo Institut, München, 1997.

Stadelmann-Steffen, I., Eder, C., Harring, N., Spilker, G., and Katsanidou, A.: A framework for social tipping in climate change mitigation: What we can learn about social tipping dynamics from the chlorofluorocarbons phase-out, Energy Research & Social Science, 82, 1–9, https://doi.org/10.1016/j.erss.2021.102307, 2021.

Stadtler, L., Seitanidi, M. M., Knight, H. H., Leigh, J., Clarke, A., Le Ber, M. J., Bogie, J., Brunese, P., Hustad, O., Krasonikolakis, I., Lioliou, E., MacDonald, A., Pinkse, J., and Sehgal, S.: Cross-Sector Partnerships to Address Societal Grand Challenges: Systematizing Differences in Scholarly Analysis, J Management Studies, https://doi.org/10.1111/joms.13053, 2024.

Stirling, A.: Direction, Distribution and Diversity! Pluralising Progress in Innovation, Sustainability and Development, STEPS Working Paper 32, 2009.

Stracke, S. and Homann, B.: Branchenanalyse Getränkeindustrie: Marktentwicklung und Beschäftigung in der Brauwirtschaft, Erfrischungsgetränke- und Mineralbrunnenindustrie, Study / Hans-Böckler-Stiftung, Nr. 368 (Oktober 2017), Hans-Böckler-Stiftung, Düsseldorf, 1178 pp., 2017.

Tàbara, D. J., Frantzeskaki, N., Hölscher, K., Pedde, S., Kok, K., Lamperti, F., Christensen, J. H., Jäger, J., and Berry, P.: Positive tipping points in a rapidly warming world, Current Opinion in Environmental Sustainability, 31, 120–129, https://doi.org/10.1016/j.cosust.2018.01.012, available at: https://www.sciencedirect.com/science/article/pii/S1877343517300854, 2018.

Turnheim, B. and Geels, F. W.: The destabilisation of existing regimes: Confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967), Research Policy, 42, 1749–1767, https://doi.org/10.1016/j.respol.2013.04.009, available at: https://www.sciencedirect.com/science/article/pii/S0048733313001534, 2013.

Tuunanen, T., Winter, R., and vom Brocke, J.: Dealing with Complexity in Design Science Research: A Methodology Using Design Echelons, MISQ, 48, 427–458, https://doi.org/10.25300/MISQ/2023/16700, 2024.

UBA: Bundesweite Erhebung von Daten zum Verbrauch von Getränken in Mehrweggetränkeverpackungen 2020, 98 pp., 2022a.

UBA: Förderung von Mehrwegverpackungssystemen zur Verringerung des Verpackungsverbrauchs: Mögliche Maßnahmen zur Etablierung, Verbreitung und Optimierung von Mehrwegsystemen, 247 pp., 2022b.

UBA: Prüfung und Aktualisierung der Ökobilanzen für Getränkeverpackungen, 492 pp., 2016.

UBA: Bewertung der Verpackungsverordnung: Evaluierung der Pfandpflicht, 244 pp., 2010.

UBA: Strukturanalyse des SERO-Systems der DDR im Hinblick auf Effizienz und Eignung unter marktwirtschaftlichen Bedingungen, Bundesministerium für Forschung und Technologie, 143 pp., 1992.

UBA: Verpackung für Getränke, 1983.

Victor, D. G., Geels, F. W., and Sharpe, S.: Accelerating the low carbon transition, The case for stronger, more targeted and coordinated international action, Brookings Institution, 2019.

Weissbrod, I. and Bocken, N. M.: Developing sustainable business experimentation capability – A case study, Journal of Cleaner Production, 142, 2663–2676, https://doi.org/10.1016/j.jclepro.2016.11.009, 2017.

Wheatley, M. and Frieze, D.: Using emergence to take social innovation to scale, available at: https://www.margaretwheatley.com/articles/using-emergence.pdf, 2011.

Winkelmann, R., Donges, J. F., Smith, E. K., Milkoreit, M., Eder, C., Heitzig, J., Katsanidou, A., Wiedermann, M., Wunderling, N., and Lenton, T. M.: Social tipping processes towards climate action: A conceptual framework, Ecological Economics, 192, 107242, https://doi.org/10.1016/j.ecolecon.2021.107242, 2022.

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[i] From the 1970s, growing environmental movements, including the Green Party's rise, highlighted waste as a major environmental issue in Germany. This led to the introduction of new waste management laws. After German reunification in 1990, the West and East German waste systems were merged. Although East Germany's SERO system was more efficient, it collapsed due to the influx of West German waste and credit fraud post-privatization (UBA, 1992). In response, the recently established Ministry of Environment passed the German *Packaging Regulation* of 1991 (I2: *policy intervention*) including an Extended Producer Responsibility (EPR), making producers accountable for managing the waste they generate (Quoden, 2010). In response to the EPR and to avoid further regulation, the private sector in Germany established a comprehensive second collection system for packaging (I3 (B): *market intervention*), funded by licensing fees of companies that produce packaging (Quoden, 2010). This is known today as the yellow bin or bag, which exists alongside the public waste system funded by taxes and fees. This Dual-System, primarily financed by industry licensing and fees (Seifert, 2011), improved the organization of packaging recycling and enabled the collection and recycling of single-use PET bottles with relatively high rates (80% collection, 66% recycling) (IFEU, 2004). However, recycling rates for other packaging types remained low (Bünemann et al., 2011).

[ii] See previous footnote.

[iii] Retrospective reporting, actually already in 1997 the share was at 71,35 %.

[iv] The introduction of the mandatory deposit for single-use bottles in 2003 (I5: *policy intervention*) initially led to a new (albeit modest) peak in reusable bottles, while single-use bottles temporarily lost market share because retailers had not prepared appropriate infrastructure, as they had not anticipated the mandate's actual implementation. However, this was short-lived.