International Journal of Operations and Prod
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Journal:	*International Journal of Operations and Production Management*
Manuscript ID	IJOPM-10-2022-0645.R1
Manuscript Type:	Research Paper
Keywords:	supply chain resilience, resilience thinking, persistence, adaptation, transformation, social-ecological systems

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Abstract

Purpose: This article seeks to broaden how researchers in supply chain management view supply chain resilience by drawing on and integrating insights from other disciplines – in particular, the literature on the resilience of social-ecological systems.

Design/methodology/approach: Before we import new notions of resilience from outside the discipline, the current state of the art in supply chain resilience research is first briefly reviewed and summarized. Drawing on five practical examples of disruptive events and challenges to supply chain practice, we assess how these examples expose gaps in the current theoretical lenses. These examples are used to motivate and justify the need to expand our theoretical frameworks by drawing on insights from the literature on social-ecological systems.

Findings: The supply chain resilience literature has predominantly focused on minimizing the consequences of a disruption and on returning to some form of steady state (often assumed to be identical to the state that existed prior to the disruption), implicitly assuming the supply chain behaves like an engineered system. This article broadens the debate around supply chain resilience using literature on social-ecological systems that puts forward three manifestations of resilience: (1) *persistence*, which is akin to an engineering-based view; (2) *adaptation*, and (3) *transformation*. Furthermore, it introduces seven principles of resilience thinking that can be readily applied to supply chains.

Originality: The article challenges traditional assumptions about supply chains behaving like engineered systems and puts forward an alternative perspective of supply chains as being dynamic and complex social-ecological systems that are impossible to entirely control.

Research limitations/implications: A social-ecological interpretation of supply chains presents many new avenues of research, which may rely on the use of innovative research methods to further our understanding of supply chain resilience.

Practical implications: The article encourages managers to think differently about supply chains and to consider what this means for their resilience. The three manifestations of resilience are not mutually exclusive. For example, while persistence may be needed in the initial aftermath of a disruption, adaptation and transformation may be required in the longer term.

Keywords: supply chain resilience; resilience thinking; persistence; adaptation; transformation; social-ecological systems

Paper type: Research paper

1. Introduction

Over the last two decades, the topic of supply chain resilience has received significant attention from researchers and practitioners alike. A valuable and impactful body of scholarly work has emerged and informed managerial decision-making, beginning with contributions by, for example, Rice & Caniato (2003) and Sheffi & Rice (2005). Subsequent contributions have greatly improved our understanding of the natural and human-made threats that a supply chain might encounter, how these threats can impact supply chain performance, and of the strategies that might be reactively or proactively deployed to mitigate disruptions to the flow of goods and services. Underlying much of this research is what has been described as an engineering-oriented view of resilience (Wieland, 2021). This is a perspective that has focused on minimizing the consequences of a disruption and on persistently bouncing back as quickly as possible to the same *status quo* that existed prior to the disruption (Wieland & Durach, 2021). This perspective has tended to emphasize recovery and on returning the system to its previous state and level of operational performance, with the speed and effectiveness of the recovery having consequences for market and financial performance.

While operations and supply chain management (OSCM) scholars have generated many important insights into supply chain resilience, the discipline can still be criticized for missing opportunities to learn from other fields and their alternative approaches to "resilience thinking". This is particularly relevant to the volatile, uncertain, complex, and ambiguous world in which we now live (e.g., Alexander et al., 2022). If the global COVID-19 pandemic has taught us anything, it is that the "new normal" will be different from the "old normal", and that adaptations or more radical transformations may well be required in order not only to survive but to flourish in an era characterized by factors such as geo-political, social, epizootic, climate and biodiversity crises (see Nikookar et al., 2021). For OSCM, this may have implications for the portfolio of products and services produced and the way in which the supply chain is configured, including how and where operations are performed as well as who has responsibility for them.

It is important to note that many other fields, such as urban planning and ecology (to name just two), have a much longer and richer history of research on resilience than OSCM (e.g., Walker et al., 2004). It can be argued that learning from these fields could greatly benefit the discipline of OSCM at the present time. Some OSCM scholars have recently recognized this by highlighting the shortcomings of a purely engineering-based view of resilience, arguing that it does not fit with the very nature of supply chains. They have identified a mismatching resilience paradigm (Adobor, 2020; Wieland & Durach, 2021) and have turned to the notion of supply chains as more complex adaptive systems (Tukamuhabwa et al., 2015). There are undoubted connections between supply chains and the social, economic, ecological, and political contexts in which they are embedded, and these connections mean that we should not demand from supply chains what we would expect from a rigidly engineered system that has been designed to persist or to quickly "bounce back to normality". Supply chains change and evolve over time; they are not immune to or independent from the systemic environment that is also changing around them (Wieland, 2021) – and this should be reflected in our understanding of supply chain resilience.

Consequently, it follows that a first important step in broadening the horizons of supply chain resilience research has been taken – there has been a critique of existing assumptions and a realization, perhaps prompted in some cases by the pandemic, of the need to think differently. The second step is to translate the existing critique into new ways of imagining supply chain resilience – achieved by learning both from within and from outside the discipline of OSCM. The primary focus of this article is therefore on seeking to learn how other fields approach resilience thinking to inform supply chain resilience research and practice.

Outside of OSCM, resilience thinking has reached a high level of maturity following the transdisciplinary efforts of ecologists and social scientists (Folke et al., 2021). Researchers have come to realize that systems such as forests, cities, and communities are open and complex and cannot be understood through the traditional closed-system approaches that were particularly prevalent in engineering disciplines (Davoudi, 2012; Holling, 1996). Attempts to characterize the resilience of these systems – now described as social-ecological systems – first led to an adaptive cycle heuristic being proposed (Holling, 1986) before the notion of panarchy was presented, which is based on several nested adaptive cycles (Holling & Gunderson, 2002). Over time, it has become evident that three manifestations of the resilience of social-ecological systems exist: persistence, adaptation, and transformation (Folke, 2006; Walker, 2020).

In this article, we seek to learn from the social-ecological systems literature and its view of resilience, emphasizing that resilience is not just about (1) *persistence*, which is akin to the engineering-based view and the continued effort to do or achieve something despite difficulties, failure, or opposition. Rather, it is also about (2) *adaptation*, that is, adjusting the existing system in response to an actual or expected change or disruption, or even (3) *transformation*, that is, the ability to transform the system's structures and processes more radically in response to changing conditions or disruptions. Our goal is not to discredit current approaches to supply chain resilience that have been observed in OSCM research. Rather, it is to enhance and augment them by drawing on and incorporating these "new" perspectives. The result is a much richer and more comprehensive framework – one that is better able to explain, retrodict, and predict events involving disruptions, change, and resilience.

We posit that this broader resilience thinking has many direct applications within the discipline of OSCM. Supply chain phenomena often result from individual social actors, from relationships between actors across organizational boundaries, and from wider interactions beyond the supply chain. The properties of supply chains are thus more akin to those of social-ecological systems than they are to the properties of deterministic engineering systems (e.g., buildings or machines). For example, a linear supply chain persists after the loss of Supplier A if an alternative Supplier B is readily available to take Supplier A's place. However, social-ecological resilience thinking – with its added emphasis on adaptation and more radical transformation – might instead consider transforming the linear supply chain into a circular one and making it less dependent on suppliers altogether. In many cases, therefore, the approaches of adaptation and transformation offered by social-ecological resilience thinking allow the OSCM discipline to discover sometimes more effective and often more fundamental solutions for the long term than the persistence approaches typically favored in the extant literature on supply chain resilience.

We begin this process of "rethinking" supply chain resilience by briefly reviewing and summarizing the current state of OSCM research into this topic. Next, this framework is challenged by drawing on five case examples of threats or disruptive events that have challenged supply chain practice and which have recently occurred: the Suez Canal blockage in March 2021; the UK last-mile fuel shortage in October 2020; ongoing sustainability debates in the automotive supply chain; cyber supply chain attacks; and, efforts to optimize food supply chains. These cases are assessed to identify the theoretical gaps exposed by applying conventional OSCM resilience research thinking. For each case, we develop or identify alternative solutions based on social-ecological resilience thinking and its strive for adaptation and transformation in addition to persistence.

By highlighting these alternative solutions, our aim is to bridge the gap between the OSCM discipline and resilience thinking and to offer a source of inspiration for new theoretical and managerial directions in supply chain resilience. Meanwhile, an ongoing stream of resilience thinking research looks at attributes that can help foster resilience "on the ground", including diversity, redundancy, connectivity, inclusivity, equity, and learning (Biggs et al., 2012; Davoudi et al, 2013). This clearly overlaps with notions of resilience in the OSCM literature, but, as we will show, also introduces some other new ideas. Such a rethinking offers the potential of uncovering new research problems as well as resolving current paradoxes surrounding supply chain resilience.

In summary, the article contributes by outlining the current state of the art in supply chain resilience research; by exploring the social-ecological perspective and seven principles derived from the social-ecological field as a new way of thinking about supply chain resilience; by unpacking five practical example applications to translate this approach to OSCM; and by proposing ways to leverage this new way of thinking in future supply chain resilience research.

The remainder of this article is organized as follows. Section 2 provides the background to the article, reflecting on the current state of the art in supply chain resilience research before we unpack the five different case examples of supply chain phenomena and interpret them from a traditional engineering or, to use social-ecological systems terminology, a persistence-based view of resilience. In Section 3, we seek to learn from the wider literature on resilience thinking before using these ideas to revisit our five examples in Section 4. This is followed by a concluding discussion of what this means for supply chain resilience research in Section 5.

2. Supply Chain Resilience: Current State of the Art

Supply chain resilience is a well-established and very well researched area of OSCM (e.g., Azadegan & Dooley, 2021; Han et al., 2020; Senna et al., 2020; Um & Han, 2021; Shekarian & Parast, 2021) where the engineering or persistence-based view of resilience has dominated. Much of this work has focused on understanding resilience and its associated constructions, such as disruptions and risk. While interest in the topic had been growing for quite some time, the COVID-19 pandemic, which started in 2019, and the supply chain disruptions of 2020-2022 sparked a major upsurge in attention on supply chain resilience. Below we point to some of the typical assumptions made in prior work, including in terms of the unit of analysis and unit of observation, and the dominant methodological approaches adopted.

While disruptions do occur in the supply chain, the focal point of the analysis in much prior research has been the focal firm. That is, research has been interested in either reducing the probability of a disruptive event from occurring or in reducing or eliminating the adverse impact of a disruption on the firm. In contrast, how the disruption affects the overall supply chain is often overlooked. Implicit to much research is also an assumption of supply chain compliance. That is, the rest of the supply chain is assumed to be willing to do or comply with whatever actions the focal firm deems to be necessary. This assumes incentive alignment and coordination across the supply chain and within the focal firm; and it overlooks some of the more complex distributions of power and control that can exist in supply chains. Seldom does the research consider situations where the focal firm, in coping with the effects of a disruption, implements actions that significantly and adversely harm the performance of one or more of its suppliers.

As observed in Li et al. (2021), when the focus does go beyond the firm level, it is often dyadic rather than holistic (i.e., the end-to-end supply chain). Thus, the supply chain is simplistically treated. Even when research recognizes the complexity of the supply chain, with its multiple tiers of buyers and suppliers, it treats the supply chain as a "one up" (one tier up to the first-tier suppliers) and "one down" (one tier down to the first-tier customer) supply chain. As noted by Choi and Linton (2011), this is a fundamentally flawed approach to treating the supply chain. Although we recognize recent interest in how supply chain disruptions promulgate through the supply chain via a "ripple effect" (e.g., Dolgui et al., 2018), this line of research is relatively new. Moreover, a "closed" system is typically presumed to exist even though there are multiple supply chains present at any point in time meaning an action that takes place in one supply chain can affect what happens in another supply chain. As noted by Wieland (2021), the supply chain is inter-linked with its larger systemic environment. Yet research has been generally limited to events that take place within the supply chain; events taking place outside of the supply chain are largely overlooked.

The focus of much prior research has been quantitative and analytical (e.g., Xu et al., 2020), partly explained by much of the work emanating from engineering, operations research, business, economics, industrial management, and computer science (Xu et al., 2020). A recent literature review by Senna et al. (2020) did however observe an increasing awareness of the human factors and the need to consider behavioural approaches and issues when studying resilience. Meanwhile, the major measure of performance in prior research is often based on cost and time (Tukamuhabwa et al., 2015). Research has been interested in reducing the time needed and the costs incurred in returning the system to the pre-disruption (or better) steady state. In contrast, measures such as sustainability have been largely overlooked, although, as noted by Xu et al. (2020), there is evidence that such matters are now being considered.

Despite the great strides that have been made by supply chain resilience researchers, recent events suggest that the traits and underpinning assumptions of research need to be re-evaluated and that a "new" approach to thinking about supply chain resilience is needed. We briefly explore five different examples of threats and disruptions to supply chains that differ in speed, scale and contributing factors, and we unpack what might constitute the traditional engineering or persistence-based view of resilience in each case. That is, the approach that has dominated to date in the OSCM literature. We will later return to these examples to consider alternative views of resilience in the light of insights gained from the social-ecological systems literature. This will enable us to consider adaptation and transformation-based views of resilience in each case.

2.1 Supply Chain Resilience as Persistence

2.1.1 The Suez Canal Blockage

On the 23rd of March 2021, the Suez Canal was blocked after *Ever Given*, a large container ship, became wedged across the waterway. Although natural conditions were a contributing factor – the vessel was subjected to strong winds of up to 40 miles per hour (approximately 65 kilometres per hour) – human error in compensating for the conditions may have also contributed to the incident (Bloomberg, 2021a; BBC, 2021b). The Suez Canal is one of the busiest and most important shipping routes in the world, representing approximately 12% of daily global trade (BBC, 2021b); and the event occurred on a single-channel stretch of the canal, which meant no other vessels could pass. It took six days to free the vessel and reopen the waterway. This might be considered a relatively short-lived disruption centred on one vessel, but it led to longer lasting, widespread supply chain shortages. *Ever Given* alone was carrying 18,300 containers. However, it was estimated that $9.6bn in trade was being held up for each day of the blockage (BBC, 2021b). Many supply chains were affected, including automotive, medical supplies, food and beverages, homeware, and sporting goods (Forbes, 2021a), with Ikea being amongst the first to warn the event was likely to add significant delays to customer orders (The Guardian, 2021a).

This example demonstrates the fragility of globally interconnected supply chains, and how a local incident directly affecting one ship can indirectly affect many other ships on a global scale, leading to non-linear, spiraling consequences. The prevailing response to the event was to adopt an immediate engineering or persistence-based approach to resume normal operations as quickly as possible. Ships backed up and waited to resume their journey while tugboats worked hard to free the vessel at high tide (BBC, 2021a). The number of tugboats involved increased day by day, with specialist boats travelling from Europe to help with the rescue operation (The Independent, 2021a). Meanwhile, dredgers attempted to clear sand and mud from around the ship. Eventually, the ship's rudder and propellers were freed, and the ship was dislodged from the banks of the canal. Shipping resumed on the 29th March 2021; but it took until early April for the backlog of waiting ships (437) to be relieved (Bloomberg, 2021b).

2.1.2 Last-Mile Fuel Shortage

A fuel crisis was sparked in the UK in September and October 2021 when several factors combined to create chaos at petrol pumps up and down the country. Although oil companies claimed that there was no shortage of petrol (gasoline), there were insufficient lorry (truck) drivers available to cover the last mile. Although it was not the only country impacted by the shortage, the UK was acutely affected. Visa and other regulatory changes following Brexit, combined with the global COVID-19 pandemic, meant that many European lorry drivers had previously left the UK (BBC, 2021c). Meanwhile, the pandemic had created a backlog of potential new drivers waiting to take their heavy goods vehicle (HGV) tests and to gain clearance for transporting highly flammable cargo (BBC, 2021c). This led to a shortage of fuel combined with a spike in demand as motorists took to panic-buying in fear of running out. Many petrol stations had to close their forecourts (stations) affecting individual citizens as well as business users, including haulage firms.

This example, where constitutional change combined with epidemiological events and consumer responses contributed to the disruption, highlights how challenges in one part of a supply chain can constrain the whole system. The UK government introduced several measures that were consistent with the persistence-based view of resilience to relieve the problem as quickly as possible. For example, it offered 300 short-term visas to overseas drivers to attract them back to the UK, wrote to former drivers to encourage them back into the industry, and temporarily used military personnel to re-establish supply to petrol stations in the most badly affected areas of the country (BBC, 2021c). Meanwhile, some companies offered drivers lucrative financial packages to obtain their services (BBC, 2021d).

2.1.3 Greening the Automotive Supply Chain

In recent years there has been an increasing focus on the detrimental environmental impact of non-renewable energy sources such as crude oil and petroleum products. Road transport is a significant user of these products, greatly contributing to carbon and greenhouse gas emissions and to pollution in urban areas. For example, it was reported at COP26 in October-November 2021 that road transport accounts for over 10% of global greenhouse gas emissions, with total emissions rising faster than in any other sector; and that the Zero Emission Vehicles Transition Council, which includes representatives from most of the world's largest automotive markets, had backed an accelerated global transition to zero emission vehicles (UN Climate Change Conference, 2021). Petrol and diesel-powered cars however still represent over 90% of total global sales (Statista, 2022). Thus, although this movement is a progressive step for the future of the planet, it represents a fundamental shift for the automotive industry that challenges the traditional design of automotive engines and threatens existing supply relationships.

This example, where the climate crisis and political intervention combine, differs from the previous examples in that there is a relatively slow, gradual onset to this 'threat' (disruption), which will affect the whole industry, and where a phased approach to responding is most likely required. A persistence-based strategy, arguably common in the last decade, is to protect the *status quo*. The car industry has, for example, lobbied against the UK's plans to ban the sale of wholly petrol- and diesel-powered cars by 2030 (GOV.UK, 2020) by questioning projections for the uptake of electric vehicles, claiming a ban would reduce total sales in the industry (The Guardian, 2021b). A persistence-based response might also involve, for example, emphasising the reliability of petrol engines, highlighting early concerns with electric vehicles, such as around battery life or the availability of charging points, and pointing to other high-carbon products that should be the focus of attention instead. Car companies have also been accused of greenwashing, overstating their attempts to protect the environment, and resisting change (Forbes, 2021b) or even cheating on emissions tests to understate their apparent impact on the environment (BBC, 2015).

2.1.4 Cyber Supply Chain Attacks

Cyber security is a major concern to organizations and nations, with many high-profile examples of data breaches being reported in the media, including the SolarWinds attack (BBC, 2020a). The European Union Agency for Cyber Security (ENISA) reported that supply chain attacks are on the rise, with major impacts on system downtimes, and on the finances and reputations of organizations (ENISA, 2021). Cyber supply chain attacks involve targeting a weak, insecure point in a supply chain's security. This might be an upstream supply chain actor with a rudimentary system, enabling access to a large number of downstream customers' data, or it might involve infecting third-party software that is pushed to customers with malware or ransomware thereby creating a backdoor into a larger number of organizations (through "watering hole" or "leap frog" attacks). In the SolarWinds case, thousands of organizations were infected with malware (BBC, 2020a).

Supply chain attacks threaten the flow and storage of information of all kinds, with subsequent impacts on the flow of goods and services. In some cases, an organization and its supply chain can become paralysed when its systems are taken over, or when data on customer orders, intellectual property or suppliers is stolen and withheld until it agrees to pay a ransom, often in the form of cryptocurrency. For example, it was reported that a ransomware attack on

Kaseya, a technology management services provider, paralysed up to 1,500 organizations (Reuters, 2021a). Meanwhile, on the 2nd February 2022, KP Snacks, a major provider of maize- (corn), potato- and nut-based snacks, revealed that it had been the victim of a ransomware attack, which it had discovered on the 28th January (The Telegraph, 2022). It warned that this would cause disruption until at least the end of March, with retailers being told that the company could not safely process orders or dispatch goods (Sky News, 2022a). In the same month, it was also reported that all of Toyota's Japanese factories had to cease production for a day after one of its component suppliers was the victim of a cyber-attack (Sky News, 2022b). Cyber criminals may also target logistics firms in a bid to disrupt air, ground, and maritime cargo transportation.

This example, where a sudden threat is posed by an external goal-directed agent that seeks to deliberately disrupt operations, exposes the fragilities introduced by technological innovations and how the initial node in which the disruption occurs in the supply chain may not be where the disruption has its biggest impact. Threats can migrate and, as we discuss later, cascade across time and space and organizational boundaries. The persistence view of resilience would focus on recovering from the attack, returning to normal as quickly as possible. This might include paying a ransom. For example, The University of California, San Francisco has admitted paying over $1m to hackers to regain access to its own data (BBC, 2020b). Although this may enable a firm to resume normal operations, it is unclear what effect it has on customers' and suppliers' confidence in the integrity of the organization's systems and what impact it has in the wider system of illegal activities. It has been reported that SolarWinds has spent the last year rebuilding its reputation (Fortune, 2021). Therefore, from a persistence point of view, paying ransoms to resume normal operations might be combined with building a robust, fail-safe single IT infrastructure that is more resistant to the threat of a future cyber-attack and with supporting supply chain partners in improving their security.

Before concluding this discussion of cybersecurity across the supply chain, it is important to recognize a unique feature of this type of disruption. These disruptions can take place at any tier in the supply chain. More importantly, they are examples of negative supply chain externalities. That is, the actions taken by a supplier operating at one tier create potential problems for a firm operating at another tier (often the focal firm). Resolving this might rely on the supplier making investments that do not primarily benefit them but the focal firm. Consequently, there is often no economic incentive to the supplier to make these investments. There have been attempts to mandate compliance. However, these efforts have not been universally successful, as described by Melnyk et al. (2018). One unintended consequence of these attempts has been that suppliers, rather than complying, may decide to leave the supply chain, thus depriving the focal firm of a potentially important, and difficult to replace, supplier.

2.1.5 Global Food Systems

The long-term sustainability of the world's food system has been questioned by the gap between the amount of food produced today and the amount needed to feed the planet's growing population by 2050, and by its contribution to the climate emergency (The Independent, 2021b; Willett et al., 2019). As a result, many food supply chains are under intense scrutiny for their environmental impact. There is a particular focus on beef production due to its high level of greenhouse gas emissions per kilogram of food (Ritchie and Roser, 2021). It is estimated that meat production in general accounts for 14.5% of greenhouse gas emissions worldwide, with red meat responsible for 41% of that total (Food and Agricultural Organization of the UN, 2022). Furthermore, cattle farming is extremely land- and water-intensive, and it has been linked to deforestation and thus the loss of biodiversity (Independent, 2021b). It is claimed that the emissions from global beef production are roughly equal to the total emissions of India (World Resources Institute, 2019) and that the land required to sustain beef production in Brazil, the world's largest beef exporter, is depleting the Amazon rainforest (Guardian, 2021c). Governments are increasingly aware of the impact of beef production on the environment and see reducing meat consumption as a cornerstone of achieving environmental targets, thereby posing a major challenge to the industry.

Meanwhile, the climate crisis itself, including a rise in global temperatures, heatwaves and droughts, is disrupting the wine industry. Rising temperatures mean grapes ripen faster, which affects harvest times and increases the amount of sugar in the grape, affecting the alcohol content and acidity of the wine (Time, 2020; The Economist, 2021). This ultimately affects its aroma and flavour. In France, the climate crisis is threatening regions like Bordeaux, which is famous for its wine production, including the Merlot grape variety (Time, 2020); and, in California, vineyards are having to contend with the rising risk of wildfires (BBC, 2020c).

This example, where production both contributes to and is affected by the climate crisis, demonstrates the deep connection between supply chains and the natural environment. The beef supply chain is threatening the environment, with the environmental consequences in turn affecting the wine industry. The persistence-based view of resilience would seek to protect or maintain the *status quo* of each industry separately for as long as possible. For example, in the beef industry, this might include promoting the benefits of (moderate) consumption, with beef being high in protein and rich in minerals, whilst ignoring the environmental impact. Meanwhile, in the wine industry, this might mean continuing with current grape varieties for as long as possible whilst attempting to mitigate the effects of the climate crisis.

2.2 Taking Stock: Implications for Supply Chain Resilience Research

When taken as a whole, these five examples illustrate challenges that current thinking around supply chain resilience may be hard-pressed to address, namely:

- Resilience must be studied within the context of an "open" system perspective. Several of these examples show that what happens in one supply chain can affect another. Consequently, issues pertaining to what happens in related supply chains must be recognized and considered within any resilience-driven research.
- Uncertainty is becoming increasingly important. To a certain extent, this insight is not new. Yet, the various examples illustrate the increasing presence and importance of uncertainty. Resilience in today's environment must first prepare for uncertainty rather than planning only for determinable risks where the distributions for the probability of the risks materializing can be estimated.
- Resilience research must go beyond the first tier. The examples show that most supply chains are extremely interconnected and interdependent. These issues of interconnectedness and interdependence must be explicitly considered when studying resilience. In several of the examples, the source of the disruption occurs beyond the first tier (i.e., at the second, third, or fourth tier). As previously noted, the lower tiers of the supply chain are largely overlooked – a state that can be explained in part by the mistaken assumption that first-tier suppliers will manage their supply chains in a manner consistent with the goals and objectives of the focal firm. Yet, the actions and problems that occur at these lower levels can and do impact the focal firm. Therefore, to reduce the probability of a disruption taking place or the impact of the disruption once it occurs, then it becomes important to focus attention on gaining access to these lower tiers. This is no mean feat since it often involves working through first-tier suppliers, who may decide not to give the focal firm the necessary access (see Wichmann et al., 2020).
- Supplier compliance cannot be assumed. As previously noted, it has been assumed that when the focal firm decides on a course of action that affects its supply chain partners, the partners willingly comply. Yet, as was discussed in the example dealing with cybersecurity across the supply chain, this is not always the case. A supplier, when faced by an action in

which the bulk of the costs are incurred by that supplier, but the bulk of the benefits are captured by the focal firm, may do more than simply not comply; they may decide to stop being a supplier. The factors contributing to supplier compliance are not well understood, and they often extend beyond economic considerations.

- Geo-political-social issues are increasingly important. Previous research into supply chain risk and resilience has recognized factors such as revolutions and political unrest. However, the examples, especially those dealing with the climate and biodiversity crises, focus on new dimensions – goals that are socially desirable and where achieving those goals may have substantial and highly disruptive effects on the supply chain. These examples force the researcher to broaden their view of factors affecting supply chain disruptions and resilience – factors such as wars or political decisions. As an example of this latter issue, consider the impact of the 2022 Russian invasion of Ukraine on Western companies doing business in Russia. As part of the coordinated sanctions program, companies such as McDonald's and Starbucks shut down operations in Russia. Yet, some companies, such as Marks and Spencer, Burger King, and hotel companies Marriott and Accor are "locked" into continuing their operations in Russia (Race, 2022).

3. The Genealogy of Resilience: Learning from Resilience Thinking in Other Fields

In this section we provide a brief history of resilience thinking in the ecology and social ecology fields – from the ground-breaking work in 1973 of Canadian ecologist, Buzz Holling, to contemporary work that distils seven principles for guiding practice and policy. We start with a brief history of resilience that identifies three notions of resilience based on persistence (akin to the engineering-based view of resilience), adaptation, and transformation. It is the latter two notions of resilience in particular that have the potential to enhance our understanding of supply chain resilience.

3.1 A Brief History

Resilience has a unique and meandering genealogy with multiple disciplinary origins (Folke 2006; Alexander, 2013). However, its contemporary popularity can be attributed to the work of Buzz Holling and, later, his colleagues that formed the *Resilience Alliance*. In a seminal article on stability and resilience in ecological systems (Holling, 1973), Holling showed that ecosystems can exist in multiple stability domains, and that resilience can be defined as the amount of disturbance that a system can absorb without losing its key functions and structures, that is, without shifting into another stability domain (Holling, 1973). As a result of this interpretation, the more flexible a system is to change, the greater its resilience.

In 1996, Holling contrasted this *ecological* view of resilience with an *engineering* view, in which the resilience of a system is measured by the time it takes for the system to return to an equilibrium state after a shock. Consequently, the more *persistent* or resistant a system is to change, the greater is its (engineering) resilience. As mentioned earlier, this has been the dominant perspective in the OSCM literature. Later, Holling and his fellow ecologists in the Resilience Alliance expanded the scope of their resilience thinking from ecology to society and developed the notion of *social-ecological* resilience (see also Davoudi, 2012; Davoudi et al., 2013; Simmie and Martin, 2010). This recognized that, in addition to persistence and also *adaptation*, where the system is adjusted in response to an actual or expected change or disruption, the development of social-ecological systems can lead to more radical *transformative* change (Reyers et al., 2018). In this transformative view of resilience, the more a system can transform its development path into a radically new one, when the former one is no longer viable or desirable, the more resilient it is.

With social-ecological resilience being grounded in complexity science, a key tenant is the conceptualization of open systems as being non-linear, self-organizing, discontinuous, and uncertain. This implies that unpredictable changes can occur not only through external shocks but also through the internal self-organizing nature of a system itself. The initial visualization of complex adaptive systems was a diagram in the shape of an infinity figure consisting of four distinct phases: growth, conservation, collapse, and reorganization (Holling, 1986). A more advanced model was later developed, which was referred to as panarchy, illustrating how open systems "function in a series of nested adaptive cycles that operate and interact […] at multiple scales from large to small, at different speeds from slow to fast and in various timeframes from short to long" (Davoudi, 2012, pp. 304).

As many scholars have pointed out, a direct translation of this model into the social domain is conceptually problematic and normatively contested (see Westley et al., 2002) for several reasons. First, people have agency and their actions are goal-oriented and intentional. Second, social relations are mediated through power and politics, which in turn raises critical questions such as 'resilience of what to what and who gets to decide', or 'resilience for whom and who gets excluded' (Porter and Davoudi, 2012). These questions come to the fore when deciding on the details of an urban resilience programme against, for example, flooding or adapting to the climate crisis. In a social context, returning to normal is not always a manifestation of community resilience because the normal may not be seen as desirable by members of the community. Similarly, adapting to shocks may be seen as a rather conservative approach aimed at surviving rather than thriving. Indeed, a resilient community may be that which strives to change the *status quo* and put in motion a transformative change by capturing the critical juncture that is created by a shock or a crisis.

Finally, it is important to underline that the three perspectives on resilience – persistence, adaptation, and transformation – are not necessarily mutually exclusive. Their desirability depends on the circumstances and, as the panarchy model teaches us, different parts of the system may behave differently either in tandem or in contradiction with each other. The key point is not to rule out the potential for transformative change within systems as a sign of failure or a lack of resilience, but to celebrate it for its potential to push the system to a new, better normal, which continues to be dynamic, contingent, and contested. The capacity of the system to do so is, therefore, a sign of resilience in social-ecological approaches to resilience thinking.

3.2 Seven Principles of Resilience Thinking

After decades of theory development and case studies conducted by the Resilience Alliance, a book was published with contributions from many of the alliance's members that distilled and assessed seven principles for building resilience in social-ecological systems (Biggs et al., 2021). The principles were identified in the context of management and governance on intertwined systems of people and nature. We present them here as inspiration for thinking more broadly about resilience in supply chains.

Principle 1 is to *maintain diversity and redundancy*. Systems with many kinds of components, such as species, actors, or sources of knowledge, are generally more resilient than systems with few components. When different components perform similar functions in the system (functional redundancy) while responding differently to disturbances (response diversity) they provide 'insurance' by allowing some components to compensate for the loss or failure of others. This principle is probably most familiar to supply chain managers who are aware that diversity in terms of cross-functional teams and redundancy in terms of multiple sources of supply can help to cope with change and disruption.

Principle 2 is to *manage connectivity*, as connectivity can be both a good and a bad thing. Modularity and polycentricity build resilience. But although well-connected systems can quickly recover from disturbances, overly-connected systems may lead to the rapid spread of disturbances, as has happened in the case of the COVID-19 pandemic. In contrast to the principles of diversity and connectivity, humans have efficiently appropriated the planet's ecosystems for food, fibre, and fuel, creating a 'global production ecosystem' that is overly connected and simplified and, therefore, vulnerable (Nyström et al. 2019). In this time of hyperconnectivity, a crisis or shock in one domain can accelerate risk in an unbounded number of interdependent domains (e.g., Cottrell et al., 2019). While this principle is also familiar to the OSCM discipline in terms of, for example, modularized components and systems, it may be less explicitly utilized in the supply chain resilience discourse.

Principle 3 is to *manage slow variables and feedbacks*. Slow changes often go un-noticed, but when they reach a certain threshold, the consequences can be large and irreversible. Therefore, it is crucial to be aware of and monitor change in the structuring variables of a system. Feedbacks are the two-way connectors between variables that can either reinforce (positive feedback) or dampen (negative feedback) change. When feedbacks change, the state of the system changes, which is why they are important to monitor and manage as well. In social systems, these feedbacks are channels of communication, which could be blocked or distorted by a lack of transparency or democratic procedures.

Here, we can take the example of the Amazon rainforest, which has historically helped stabilize the climate through its vast absorption of CO_2 and circulation of moisture. Today, the combined effects of droughts and deforestation caused by the production of soy for beef supply chains has pushed the Brazilian part of the Amazon to a threshold where it has turned into a net-emitter of greenhouse gases, increasing the global warming that causes droughts (Nobres et al., 2021). This changing feedback loop is certainly monitored by scientists, but because the resulting change is slow on a business timescale, the response from regulators, investors and consumers is weak, and because powerful companies lobby against regulation to protect their profits, their monitoring has not yet led to any positive action. Consequently, deterioration of the Amazon continues and its ecosystem role has transformed from being a carbon sink into being a carbon emitter. Although clearly applicable to the OSCM context, we are unaware of any examples of OSCM research that relate explicitly to this principle.

Principle 4, to *foster complex adaptive systems thinking*, and Principle 5, to *encourage learning*, are about enhancing human capacity to adopt the first three principles. A complex adaptive systems (CAS) approach means accepting that within a social-ecological system, several connections are occurring at the same time at different levels. It also means accepting unpredictability and uncertainty, acknowledging a multitude of perspectives. Because social-ecological systems are always in the making, there is a constant need to experiment, revise existing knowledge, and stimulate learning.

Finally, principles 6 (*broaden participation*) and 7 (*promote polycentric governance*, i.e., multiple, interacting governing bodies with autonomy and flexibility to create and enforce rules) are about enabling collective action and creating a foundation for learning, participation, institutional diversity, modularity, flexibility, and redundancy. It should be recognized that polycentricity also increases transaction costs and can challenge legitimacy, transparency, and accountability. The nature of supply chains means they are inherently polycentric, but it has rarely been discussed in the literature how this could be leveraged to generate resilience. For example, addressing challenges related to supplier compliance could benefit from this principle, as dialogues across the supply chain would likely increase the chances of finding feasible solutions towards resilience for all. Moreover, broadening participation, for example by including worker communities in supply chain decisions, has been a part of debates related to social responsibility rather than supply chain resilience.

4. Applying Alternative Approaches to Supply Chain Resilience

In this section, we use ideas taken from the literature outside of OSCM, namely the adaptation- and transformation-based views on resilience, to briefly revisit the earlier examples. And in so doing, we also attempt to transfer resilience principles from the social-ecological resilience literature to the context of supply chains. Our core arguments are summarized in Table I.

[Take in Table I]

4.1 Supply Chain Resilience as Adaptation

The adaptation-based view involves adjusting the existing system in response to an actual or expected change or disruption. During the Suez Canal blockage, several temporary adaptations were made by users of the waterway that are consistent with the adaptation-based view. For example, some logistics companies started to re-route their ships around the Cape of Good Hope, the southern tip of Africa, to avoid the Suez Canal and get supply chains moving again, even if this increased shipping times to Europe by around eight days (BBC, 2021b). Air freight was also used as a short-term solution for some goods despite the additional cost and environmental impact. These adjustments enabled firms to continue to ship goods between Asia and Europe. Firms have also explored longer term adaptations to their logistics systems, such as by establishing alternative, permanent shipping routes. Meanwhile, not only are users of the waterway adapting, but the waterway itself is being adapted. New tugboats and dredgers have been procured (Reuters, 2021b), while parts of the waterway are being widened before 2024 and the stretch of the waterway were a second channel is accessible is being extended

(Reuters, 2022). These strategies resonate well with *Principle 1*, which is about redundancy and diversity, implemented here in terms of redundant routes and diversity in modes of transport.

Returning to the last-mile fuel shortage, some petrol stations took adaptive measures to maintain their offering to customers, such as by placing a limit on how much each customer could purchase to ration supplies. Plans were also put in place to train 4,000 more HGV drivers and to streamline the process for obtaining a licence (BBC, 2021c). These responses are in line with *Principle 1* on providing redundancy and *Principle 6* on broadening participation. In the automotive industry example, one adaptation would be to develop lower emission engines that reduce a car's impact on the planet, which is in line with *Principle 5* (encourage learning). This might involve adjusting existing designs that enable supply relationships to be maintained; however, it is not a long-term solution given government plans to phase out petrol- and diesel-powered cars and incentivize drivers to switch to electric vehicles, including so-called "plug-in" grants (GOV.UK, 2022a and 2022b). Meanwhile, to guard against cyber-attacks, a firm may adapt its security by improving systems monitoring to gain an early warning of hacker activity, continually improve its processes to be a moving target for hackers, and develop a duplicate, back-up data storage system in a separate location to increase its ability to recover – again arguably aligned with *Principle 1*.

Finally, in the food systems example, a meat producer might look to rebalance the mix of meats that it produces, putting greater resources into meats that are less harmful to the environment, such as poultry (*Principle 1* and *Principle 5*). Meanwhile, wine producers may look to diversify (*Principle 1*) into new grape varieties that are more suitable to the changing local climate (The Independent, 2020). In Bordeaux, for example, there are now experimental laboratories searching for new flavours of wine and varieties of grape that can withstand higher temperatures (Time, 2020). Wine producers might alternatively look to relocate to another location that offers them better growing conditions and more support for their existing produce and business model.

4.2 Supply Chain Resilience as Transformation

The transformation-based view involves a more radical and fundamental departure from the existing system in response to changing conditions, threats, or disruptions. Social-ecological transformations require systemic shifts in mental models and paradigms as well as changes in institutions, management routines, and resource flows (Westley, 2013). In the context of the Suez Canal blockage, this might involve the longer-term response of rethinking the globalised configuration of supply chains and developing much more localised systems where production and consumption are in proximity, thereby avoiding the need for disruption-prone and complex logistical operations. It might also involve rethinking outsourcing decisions and the use of well-established strategies such as just-in-time production. A greater emphasis on circular supply chains and both the re-use and repair of goods would also reduce the need for production and, thus, transportation from wherever the operation takes place. Such approaches, however, require taking slow variables and feedbacks into consideration (*Principle 3*), an approach not typically discussed in the supply chain resilience literature. This involves simultaneously taking long-term macro developments at the political-economic, societal, and planetary levels into consideration when making meso and micro supply chain and operational decisions (Wieland, 2021).

Meanwhile, in the last-mile fuel shortage example, a long-term transformation-based response at a national level might be to switch to other sources of fuel that do not rely on the supply of petrol or diesel. At this point, two of our examples converge on the obvious transformation taking place in the automotive industry, with firms moving to electric-powered engines.[1] This is having a profound effect on supply chains (PwC, 2022) – with major implications for research and development, technology investment, capabilities, and relationships – and represents a large transformation in the industry. Various well-known car manufacturers have now pledged when they will switch to selling only electric vehicles, including Jaguar (2025), Lotus (2028), Volvo (2030), and General Motors (2035) (BBC, 2021e). While some automotive plants are closing, others are receiving huge investments to aid the transformation. For example, Ford is to invest £230m in its Halewood plant in the UK to produce electric power units by 2024, safeguarding 500 jobs (BBC, 2021f). Meanwhile, Nissan will expand the production of electric vehicles at its plant in Sunderland, UK, creating 1,650 new jobs (BBC, 2021g), supported by the enlargement of Envision's nearby Gigafactory that will supply the batteries (The Guardian, 2021d). Arguably the most well-known electric car manufacturer, Tesla, has not undergone a radical transformation given that it was 'born electric' but it did have a transformational vision for the future of the industry from the outset. More radical transformations in the industry could include expanding the use of product-service systems approaches to accessing shared cars that reduce the overall number of vehicles needed. Even larger transformations that co-occur across multiple levels could be the vision of

[1] On a different scale, electric vehicles can be interpreted as an adaptation that keeps the dominant model of individual cars alive, whereas transformation would enable a shift towards other modes of transport.

a car-free future with self-driving public transportation and a focus on bike lanes – arguably in line with *Principle 5*. Urban areas could then be re-imagined to reduce emissions, such as through greater pedestrianization. It should be clear that such solutions would be overlooked by following traditional approaches of supply chain resilience.

To avoid the threat of a supply chain cyber-attack, an organization might look to migrate to a completely different approach to trading and storing data. As unlikely as it seems, this might even be to a wholly paper-based solution to avoid the use of technology altogether. This would be one way of avoiding the system being overly connected, in line with *Principle 2*.

Finally, in the food systems example, radical transformation might alter the landscapes of rural areas where land is re-purposed from cattle to crops or restored to natural habitats and forests. Meanwhile, a more holistic approach could be adopted towards the health of the global food system, rather than pitting, for example, beef supply chains off against the wine industry. At a local level, this could be combined with a shift in culture away from the consumption of beef towards accessing protein, including via plant-based products. For example, Danish Crown, a major meat processing company that has been primarily focused on processing pork and beef, recently launched its first plant-based range of ready meals and ingredients. In addition, producers of wine may look to create alternative beverages, such as from other fruits, whilst influencing consumer attitudes towards more climate-suitable products.

From all these considerations it becomes clear that the distinction between persistence, adaptation, and transformation derived from the social-ecological systems literature also contributes to expanding the solution space in the OSCM discipline. Although some of the solutions presented here might have been found intuitively without our framework from social-ecological systems thinking, the framework can help ensure that such solutions are now discussed systematically and consciously.

5. Conclusions

Recent research and world events have prompted a need to think differently about the resilience of supply chains. This article forms part of the response to this need by seeking to learn from notions of resilience in the literature outside OSCM – specifically the literature on social-ecological systems. Through the five examples of threats or disruptive events that have challenged supply chain practice, we have demonstrated the utility of this thinking for supply chain scholars, including the notions of supply chain resilience as persistence, adaptation, and transformation, and the seven principles for designing resilience systems.

The notion of what constitutes resilience changes depending on what assumptions academics and practitioners make about the properties of a system and its boundaries – in our case, a supply chain and its connections to the wider environment in which it is embedded. Challenging traditional assumptions provides new opportunities for future research on supply chain resilience: do we wish to believe that a supply chain behaves like an engineering system, that its properties are thus like those of a system designed by engineers from the ground up? Such systems are static and closed and can therefore be controlled. Here, supply chain resilience implies going back to normal as quickly as possible – that is, to persist. Or, and this is what broader resilience thinking teaches us, do we wish to believe that a supply chain behaves more like a dynamic and complex social-ecological system that is impossible to entirely control? If so, then adaptability and, more radically, transformability emerge as reinterpretations of supply chain resilience. We advocate this latter view, especially for long term responses to disruptive events, and argue that OSCM scholars should focus on this perspective in future research (see Wieland and Durach, 2021) to supplement all of the contributions that have already been made to our understanding of supply chain resilience.

As soon as supply chains are interpreted as social-ecological systems, the question arises as to how academics can transfer the ideas of resilience thinking to the context of a supply chain. The *Handbook of Research Methods for Social-Ecological Systems* by Biggs et al. (2021), which contains contributions by resilience scholars from multiple fields, provides an overview of many methods and techniques that will already be familiar to OSCM scholars, including action research, cross-case analysis, data mining, etc. But it also points to approaches that OSCM scholars may be less familiar with, including facilitated dialogues, futures analysis, participatory modelling, and state-and-transition modelling to name a few. This may prove helpful as we look to develop new theory about supply chain resilience.

Following the approach of Stephens et al. (2022), the achievements of resilience thinking in other fields could be transferred to OSCM using social-ecological metaphors. There is already a lot of literature on the social-ecological interpretation of other systems (e.g., forests and cities) in other fields, and this could be transferred to supply chains using these systems as metaphors. For example, what if we interpreted a supply chain as a "city" and its actors or firms as the "citizens" of that city, and so on? This could contribute to very insightful theory building about supply chain resilience and represents another important opportunity for future research on supply chain resilience.

Resilience thinking has put forward seven resilience principles that help drive the adaptability and transformability of social-ecological systems. Some of these principles can be recognized, and have already co-evolved, in the supply chain resilience literature. For example, Principle 1, to maintain diversity and redundancy, is familiar to OSCM scholars and practitioners alike. For ecosystems, this principle means, for example, that a forest should not consist of monocultures. For supply chains, this principle means, for example, that several suppliers can stand in for each other in the event of a failure. However, we could not think of analogous applications in the OSCM literature for some of the other principles. One task for future OSCM research could therefore be to find analogies for principles that have not yet been discovered in this discipline – such as Principle 3, concerned with managing slow variables and feedbacks, or arguably Principle 7, concerned with promoting polycentric governance.

For practice, the article encourages managers to think differently about supply chain resilience (i.e., beyond the engineering-based view), and about how they can manage their responses to a disruption in the short and long term. Managers should be aware that the three manifestations of resilience described are not mutually exclusive and may be used sequentially over time or in combination at different levels. For example, while persistence may be needed in the initial aftermath of a disruption, adaptation and transformation may be required in the longer term to reduce the potential of a disruption reoccurring. Alternatively, transformation may be required at a micro level of analysis, such as at an operation or component level, to enable persistence at a more macro level of analysis, such as the supply chain. Managers should consider how they can develop this type of resilience thinking – the three manifestations of resilience and seven principles – within their operations and supply chains, and how they can develop the capabilities necessary to drive radical change where needed.

Finally, this article is an example of how new ideas often come from breaking the mold of traditional thinking and embarking on academic adventures. In our case, the adventure was getting academics to work on an article about a phenomenon they have been researching for a long time, but in three very different areas (OSCM, urban planning, and social ecology). It is encouraging to know how quickly disciplinary silos can be broken down when all parties are willing to do this, and how much one can learn by looking over a neighbor's fence. So let us not build them too high. Based on this experience, we can only encourage all readers of these lines to also join cross-disciplinary research projects, thereby enabling new perspectives on (supply chain and other types of) resilience to be developed and our theoretical horizons to be broadened.

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Table I: Example Threats and Disruptions to Supply Chains from a Persistence, Adaptation, and Transformation Perspective

Example	**Description of the Problem**	**Persistence** *The continued effort to do or achieve something despite difficulties, failure, or opposition*	**Adaptation** *Adjustments to the existing system in response to an actual or expected change or disruption*	**Transformation** *The ability to more radically transform the system in the face of changing conditions or disruptions*
The Suez Canal Blockage	The Suez Canal was blocked for six days following the grounding of the ship *Ever Given*, creating a huge backlog of ships and causing supply chaos.	Ships queued awaiting the waterway's reopening. A primary focus on removing the ship as fast as possible to re-establish the old steady state and supply route.	Re-routing ships or using alternative short-term forms of transportation; and creating a wider or extended second channel in case the problem repeats.	Challenging the way in which business is organised in a global context; shifting towards a greater emphasis on localization, reuse, and repair.
Last-Mile Fuel Shortage	A shortage of lorry drivers in the UK following employment law changes after Brexit and the effects of COVID-19 led to fuel shortages across the country as fuel could not be delivered to stations.	Using the military to resume the supply of fuel; offering short-term visas; and providing financial incentives to lorry drivers in Europe to come back to the UK.	Training more drivers; streamlining the licence application process; and rationing supplies.	Switching to other sources of fuel such as electric that do not rely on the supply of petrol and diesel.
Greening the Automotive Supply Chain	The non-sustainable use of oil in petrol- and diesel-powered cars has created a sector-wide push towards zero-emission alternatives.	Continuing to popularise the current car industry and high oil-consuming cars whilst questioning the viability of zero-emission solutions.	Developing more fuel-efficient engines.	Producing electric powered cars; moving towards service-based access to cars that reduce the number of vehicles needed; and re-imagining urban areas to reduce emissions.
Cyber Supply Chain Attacks	The increasingly common phenomenon of companies being held to ransom over access to their data or systems whereby weak links in the supply chain are targeted.	Paying ransoms to resume operations; building a stable, fail-safe single IT infrastructure; supporting vulnerable supply chain partners.	Improving systems monitoring; being a moving target for hackers; maintaining a duplicate, back-up data storage system.	Migrating to an alternative approach to storing data (perhaps even radically to a paper-based solution to avoid the use of technology altogether).
Global Food Systems	Food supply chains affect the environment, and the environment in turn affects food supply chains. The environmental impact of meat production threatens the scale of the industry while climate changes mean the types of grapes that will grow effectively in a region will change over time.	Advertising meat consumption whilst ignoring the environmental impact. Continuing to produce wine as before whilst using engineering solutions to maintain ideal growing conditions for as long as possible.	Rebalancing the mix of meats produced towards those that are less harmful to the environment, e.g. from beef to poultry. Changing the type of wine produced in response to the changing climate.	Taking a holistic approach to the global food challenge. Shifting the emphasis of consumption towards accessing protein rather than eating meat, including producing more plant-based protein. Influencing consumer attitudes towards more climate-suitable products than wine.