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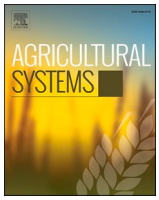

Transitions through the dynamics of adaptive cycles: Evolution of the Finnish agrifood system

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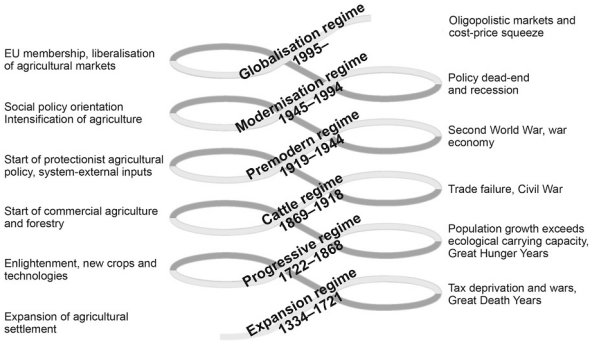
HIGHLIGHTS

- A qualitative analysis of 700 years of Finnish agrifood system's history was conducted.
- Adaptive renewal cycles capture the regime shifts in the Finnish agrifood system.
- The elements of growth have turned to seeds of destruction during each regime.
- Regime shifts were driven by loss of resilience.
- Metabolic changes induced the most far-reaching regime shifts.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: The escalating sustainability problems of the current agrifood regime call for a radical, systemic transformation. Such a transformation implies a move into a new stability domain, defined by a new set of systemic attractors. These transformations can be conceptualised as regime shifts.

OBJECTIVE: In this study, we explored the history of the Finnish agrifood system in order to learn from the past transformations of the system and to inform the current attempts to steer its development in a more sustainable direction.

METHODS: We conducted a qualitative analysis on literature discussing the history of the Finnish agrifood system by utilising the concept of the adaptive cycle, which captures the cyclicity of the evolution of social-ecological systems.

RESULTS AND CONCLUSIONS: We identified six regimes from the 14th century onwards: Expansion (1334–1721), Progressive (1722–1868), Cattle (1869–1918), Premodern (1919–1944), Modernisation (1945–1994) and Globalisation (1995–). During each regime, the evolution of the system organised around specific attractors which initially opened up new possibilities for the actors, but over time, the very same attractors became the main source of vulnerability in the system. Along with the system's maturation, path-dependency created rigidity, escalating sustainability problems and decreasing room for manoeuvre for the system's actors, concomitantly decreasing the system's resilience. When an external shock related to climatic conditions, economic turbulence or wars coincided with such a rigidity, the system collapsed, the consequences

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of which span from food shortages to large-scale, deadly famines. The collapse of the old regime opened up the window of opportunity for a regime shift. The most profound regime shifts were related to changes in the system's metabolism and trade orientation.

SIGNIFICANCE: While the conservation phase of the adaptive cycle increases systemic vulnerabilities, it also offers an opportunity for systemic transformation. Allowing the adaptive cycle to play out on smaller scales—such as at the level of farm systems—helps to avoid collapse on the scale of the whole food system. The current agrifood regime in Finland indicates strong path-dependency and rigidity, manifesting a conservation phase, to be followed by release and reorganisation. This observation calls, first, for considering the resilience of the current system to anticipate a crisis and, second, for outlining alternative visions for the sustainable future of the agrifood system.

1. Introduction

During the past century, agrifood systems have undergone major changes globally. In the processes of modernisation, industrialisation and globalisation, locally oriented, more or less self-sufficient systems have transformed into systems tuned around relative competitive advantage, ever-increasing productivity fuelled by fossil and synthetic inputs, and dependence on the international trade of foodstuffs (McMichael, 2009; Oosterveer and Sonnenfeld, 2012; Kummu et al., 2020). While these developments have made it possible to feed a population that has more than quadrupled from 1920 to 2020, they have also contributed to a number of persistent problems, from biodiversity loss to environmental degradation and climate change, as well as social problems such as unequal nutrition and animal welfare issues (Pretty, 2008; Marsden and Morley, 2014; Eakin et al., 2017). To address these problems, it is of utmost importance to understand their systemic origin (Rotmans and Loorbach, 2009; El Bilali, 2018; Béné et al., 2019).

The shift towards a more sustainable future calls for a radical departure from the current ways of production and consumption within the agrifood system: a societal, systemic transformation. The questions of societal transformation are addressed within the field of transition studies, which explore causes, effects and processes related to the evolutionary dynamics of social systems (Geels and Schot, 2010; Loorbach et al., 2017; Ollivier et al., 2018; Köhler et al., 2019).[1] Understanding how and why systems undergo radical transformations calls for long-term historical analysis (Fraser and Stringer, 2009; Parsons and Nalau, 2016; Nicoll and Zerboni, 2020). Such an understanding can prove to be pivotal for the current attempts to steer the sustainability transition of our contemporary social systems (Garud and Gehman, 2012; Van Bers et al., 2019). However, the majority of transition studies in the field of agrifood systems as well as beyond them tend to be concerned with the dynamics of the present-day transition processes or limit their investigations to specific transition periods in history and the dynamics prevailing in those relatively short timeframes. Accordingly, Van Bers et al. (2019) argue that in order to navigate the transition of agrifood systems towards more sustainable pathways, far more empirical research is needed about (a) their historical transformations, and (b) the incremental vs. radical forms these transitions can take.

What constitutes a radical transformation of a social system remains ambiguous in the contemporary transition literature (Geels and Schot, 2007; Feola, 2015; Hölscher et al., 2018). Such transformations essentially relate to the stability of regimes, which can be seen as the dominant structural configurations of social systems prevailing across certain time periods. Regimes are characterised by stability and path-dependency anchored around strong social forces such as norms, routines, power relations and technologies (Loorbach et al., 2017). Regimes are path-dependent and resistant to change, but not immutable; thus, a regime shift – a significant change in the structural configuration, processes and functions of a system – can be seen to constitute a radical transformation, while incremental transitions may change some dimensions of the regime yet leaving their basic structures untouched.

Over the long term, the transition dynamics in social systems tend to take a cyclical form, as indicated by, for example, Schumpeter's cycles (Schumpeter, 1934) and Kondratieff's waves (Nefiodow and Nefiodow, 2017). Analysis of the macro-level development taking place within food systems (the food regime theory) has indicated that food systems are not in a state of constant flux, but they are characterised by multiple stability domains and consequent transformations (McMichael, 2009). In other words, social systems tend to spend considerable periods in a state of incremental developments that do not challenge the essence of the regimes, but these periods of stability are at times interrupted by events that reconfigure the structural foundations of the regimes.

A prominent framework for addressing both the cyclic nature of evolution of the social systems, as well as the multidimensional dynamics giving rise to It, is the concept of the adaptive (renewal) cycle (AC). The adaptive cycle is a heuristic model that captures the life cycle dynamics of social-ecological systems through phases of exploitation, conservation, release and reorganisation (Holling and Gunderson, 2002; Folke, 2006; Walker and Salt, 2006). As an integral part of resilience theory, it captures the dynamics occurring at multiple spatial and temporal scales across a system; this hierarchy of nested scales is referred to as panarchy (Holling and Gunderson, 2002). The theory holds that regime shifts take place as a result of a system exceeding resilience threshold—with resilience understood as "the capacity to absorb disturbance, to undergo change and still retain essentially the same function, structure, and feedbacks" (Walker and Salt, 2006: 32)—and entering a new regime or stability domain (Holling, 2001). The concept of adaptive cycle was originally coined within the field of ecology (Holling, 1986), and it was later adopted by social scientists to uncover and interpret development patterns of various kinds of social-ecological systems. In the context of agrifood systems, the adaptive cycles have been used to illustrate long-term transition dynamics observable in various geographical regions, as in the analysis of systemic lock-ins (Allison and Hobbs, 2004), spatiotemporal change dynamics and transformations (Vang Rasmussen and Reenberg, 2012; Winkel et al., 2016; Antoni et al., 2019), the resilience of local agroecosystems (Abel et al., 2006; van Apeldoorn et al., 2011; Tittonell, 2020) and agrarian soil use (Teuber et al., 2017) as well as industry restructuring (Sinclair et al., 2014).

In this study, our aim is to explore the long-term evolution and transition dynamics within an agrifood system. Our case concerns Finland, a developed country in Northern Europe. More specifically, we aim at identifying regime shifts from the history of the Finnish agrifood system, starting from the 14th century, as well as the conditions predating the radical changes of the system. Using the adaptive cycle heuristic as a theory of change in the Finnish agrifood system has significant value for revealing the key drivers and patterns of change across time, and the lessons learned might have value for other countries and agrifood systems as well, regardless of whether or not they have experienced similar transitions over time or have operated in similar regimes. Finland is an interesting target of investigations for a variety of reasons.

[1] The literature discussing large-scale changes of social systems uses both terms *transformation* and *transition*. The difference between the two is not clear-cut, but studies on social-ecological systems generally refer to *transformations* whereas the term *transitions* is commonly used by the socio-technical stream (Hölscher et al., 2018).

On the one hand, it serves as an example of the historical transformation trajectory observable across the Global North, with a changing metabolic basis of the agrifood system and the interrelated, escalating sustainability problems and increasing efforts to address them. On the other hand, the Finnish agrifood system has witnessed many periods of food-related vulnerability and crises, which are partly related to Finland's northern location at the edge of the bread-grain cultivation zone. To analyse the historical evolution of the Finnish agrifood system, we conducted a qualitative survey of the agrifood and historical literature within the framework of the adaptive cycle, depicting its development from the 14th century all the way to the present day. Our paper is organised as follows. In section 2, we discuss the theoretical background: the theory of complex adaptive systems and adaptive cycles, and how these theoretical frameworks can be utilised in analysing the transition dynamics of social systems. In section 3, we present our methodological approach. In section 4, we present our results concerning the identified regimes and regime shifts, as well as the system dynamics that have given rise to these shifts. In section 5, we discuss the relevance of our findings especially from the viewpoint of sustainability transitions.

2. The dynamics of adaptive cycles in social-ecological systems

Agrifood systems are a type of social-ecological system, but they are also complex adaptive systems (CAS). Complex adaptive systems are open systems that exchange matter, energy and information with other systems, lack central coordination and self-organise around systemic functions (Byrne and Callaghan, 2014; Boulton et al., 2015), such as food provision in the case of food systems (Hodbod and Eakin, 2015). These systems alternate between several equilibria or steady states (Holling and Gunderson, 2002; Folke, 2006). These alternative equilibrium states converge around attractors. The system dynamics take place within the power field set up by attractors, forming a basin of attraction (Kuhmonen, 2016). Depending on the system and the context, attractors can take various forms: norms, practices, technologies and so on. Basins of attraction are manifestations of a system's path-dependency, as they limit the possibilities towards which a system can evolve within a specific development trajectory (Kauffman, 1993). Thus, they can be conceived of as 'cups' or 'valleys' in which the system lives.

Within the transition literature and political economy, similar dynamically stable configurations of social systems are captured by the concept of regime. Here, the concept of regime depicts the patterned development trajectories of socio-technical systems featured by cognitive routines, regulations and standards, the interlinkages between lifestyles and technologies, sunk investments as well as path-dependencies related to investments in machines, infrastructures and competencies (Geels and Schot, 2007). In this way, the cyclical evolution of complex adaptive systems can be traced back to consecutive regimes (equilibrium or steady states) and regime shifts (transformations). According to resilience theory, a resilient regime remains within the state space defined by a set of attractors (Gunderson and Holling, 2002; Walker and Salt, 2006). When the system loses its resilience, typically resulting from an exogeneous shock coupled with internal vulnerability, the threshold delineating this state space—the 'cup' within which the system lives—is crossed, and the opportunity for a regime shift opens up (Walker and Salt, 2006). In this situation, the system may either return to its earlier steady state, defined by the same attractors as before, or reorganise around a new set of attractors (Gunderson and Holling, 2002).

The evolutionary dynamics of social-ecological systems underlying regime shifts can be conceptually modelled using the adaptive (renewal) cycle (AC; Fig. 1). The AC can be seen as a life cycle model entailing the imminent stages of birth, growth, maturation and decline. The equilibrium states or regimes – captured by a basin of attraction – form during the reorganisation phase (α), grow during the exploitation phase (*r*), stabilise during the conservation phase (K) and decline during the release phase (Ω) (Walker et al., 2002; Sundstrom and Allen, 2019). This sequence is indicative in the sense that not all systems at all cycles pass through all of the phases in consecutive order (Walker and Salt, 2006). According to this model, a regime shift is most likely to take place as a result of a systemic collapse taking place in the release phase, which opens up the window of opportunity for the system to reorganise towards a new stability domain. Thus, the 'front loop' consisting of exploitation and conservation phases represents incremental change, while a radical transformation and a regime shift can follow from the system entering the 'back loop', consisting of release and reorganisation phases.

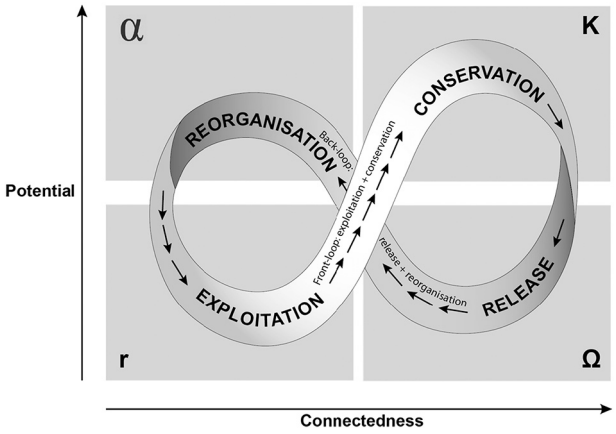

Fig. 1. The logic of the adaptive cycle (adapted from Gunderson and Holling, 2002, 34).

In the *exploitation phase* (r), new opportunities and resources are available for the system agents to exploit (Walker and Salt, 2006). This phase is marked by continuous accumulation of different forms of capital facilitated by self-reinforcing feedback loops between the system's components, which leads to accumulating resources, know-how and welfare (Renfrew, 1984; Gunderson and Holling, 2002; Walker and Salt, 2006; Fath et al., 2015; Faulseit, 2016). At the beginning of the exploitation phase, the system is weakly regulated and interconnected, but the connectedness of the system increases along with the system's growth (Walker and Salt, 2006). Due to these positive feedback loops, resources and power centralise to the hands of the most successful actors (Gunderson and Holling, 2002; Walker and Salt, 2006)—peripheralising less powerful actors (such as farmers within the food system; Kuhmonen, 2020).

Accumulation and centralisation of different forms of capital indicates a transition to the *conservation phase* (K) (Walker and Salt, 2006). The conservation phase typically means "a move toward more specialization and greater efficiencies or large economies of scale: bigger machines, bigger outputs, smaller costs per unit, larger profits over longer timeframes" (Walker and Salt, 2006: 77). Increasing connectedness creates rigidity within the system and slows down the system's growth rate (Gunderson and Holling, 2002; Walker and Salt, 2006). Acting otherwise becomes increasingly difficult, as the search for efficiency eliminates diversity and alternative ways of doing (Walker and Salt, 2006). Reinforcing feedbacks maintain the system's growth in the exploitation phase, but growth also creates unintended consequences. These can turn some of the reinforcing feedbacks to balancing feedbacks, which then resist change in a particular direction. As a result, the growth of the system eventually slows down, and path-dependency of the regime consolidates. The resulting centralised system is tuned around efficiency, has eliminated redundancy, and has its capital tightly bound into existing structures. The resilience of such a system is low, and that is why any external disturbance—such as drought, political unrest, major institutional change or economic recession, but also a relatively small disturbance—can push the system over a critical

threshold and cause a release phase (Allison and Hobbs, 2004; Abel et al., 2006; Walker and Salt, 2006; Chaffin and Gunderson, 2016; Hartel et al., 2015). In other phases of the cycle, the system is more resilient to such disturbances and is less likely to cross a critical threshold that could lead to collapse of the system.

In the *release phase (Ω),* natural, social and economic capital leak out of the system, which leaves room for uncertainty or even chaotic conditions (Walker and Salt, 2006). The conditions are favourable for the reorganisation and emergence of a new regime. During the *reorganisation phase* (α), the system converges either around the same attractors as before or around new ones, thus moving towards a new basin of attraction. Due to the loose organisation of the system, the reorganisation phase is favourable to the emergence of new actors, new modes of organisation and governance, and new kinds of networks between the actors (Walker and Salt, 2006; Fath et al., 2015). Resources released in the collapse of the previous regime are available to be harvested, but the process of reorganisation can benefit from receiving additional activation energy from the broader scales in the panarchy structure, or, in some cases, from beyond the focal system (Gunderson et al., 2002; Abel et al., 2006; Vang Rasmussen and Reenberg, 2012; Fath et al., 2015). The concept of panarchy refers to the hierarchy or embeddedness of nested scales (Holling et al., 2002): in the case of food systems, such scales could include global trade systems, national level food systems (which is the focus of inspection in this study), regionally organised supply chain systems and, finally, farm systems. The dynamics of adaptive cycles are affected by similar dynamics occurring both at the broader and lower levels of the system; at the broader level cycles tend to last longer than at the lower levels (Holling et al., 2002). The resulting pattern of interactions is called 'revolt and remember'. The term *revolt* refers to the faster renewal rate of smaller-scale systems affecting cycles at broader scales, whereas the term *remember* refers to the confining effect of how broader scales condition the options available for systems at smaller scales (Gunderson et al., 2002; Holling et al., 2002).

During the four phases, a system manifests diverging levels of connectedness, potential and resilience (Holling, 2001; Sundstrom and Allen, 2019). The concept of *connectedness* captures the amount and quality of interdependencies and feedback loops in the system (Holling and Gunderson, 2002). The degree of connectedness generally grows along with the maturity of the system through the organisation, structuration and institutionalisation of the behaviours of the system agents and their interactions (Walker and Salt, 2006). Connectedness peaks in the conservation phase and collapses in the release phase. The concept of *potential* refers to the options available for the system agents (Holling, 2001). In the conservation phase, the system is rich in resources but poor in options, whereas in the release phase there is a lot of latitude for improvisation, initiative and innovation (Fath et al., 2015). In a more abstract setting, potential can be seen to capture the oscillating power balance between structure and agency (see Giddens, 1984; Archer, 2000). A *resilient* system is able to navigate among these phases while retaining its ability to fulfil its systemic functions (Holling, 2001; Meuwissen et al., 2019). However, resilience or the capacity to adapt often weakens because of the growing rigidities during the conservation phase, which may cause the system to enter the release phase after losing resilience partly or completely (Walker et al., 2006).

In sum, in the light of the theory of resilience and adaptive cycles, a regime shift, representing a radical systemic change, is most likely to result from a collapse of the system of some magnitude. Such a collapse typically results from a loss of resilience, which drives the system over the threshold delineating the system's basin of attraction. Systems are most vulnerable and thus prone to lose their resilience at the late conservation phase of the adaptive cycle due to growing rigidity and (over)-connectedness of the system elements.

3. Data and methods

To depict the evolutionary dynamics of the Finnish agrifood system and identify its major regime shifts from the 14th century to the present day, we conducted a qualitative thematic analysis by reviewing literature on the history of the Finnish agrifood system. By 'agrifood system' we mean the whole system of production and consumption of food, including both its material and cultural dimensions that can assume different manifestations over time. Thus, the Finnish agrifood system is one that aims at feeding the population residing within the country's boundaries. We reviewed approximately 100 items from the literature, ranging from extensive accounts of the history of Finnish agriculture to detailed research reports concentrating on some specific aspects of the

Table 1
Literature referred to in the analysis by regime.

Regime	Literature
1. Expansion regime (1334–1721)	Huhtamaa and Helama, 2017; Jutikkala, 1958; Katajala, 2003; Korhonen, 2003; Korpela, 2012; Kuisma, 1997; Kylli, 2021; Lappalainen, 2021; Muroma, 1991; Mäkelä-Alitalo, 2003; Niemelä, 2008; Nummela, 2003; Orrman, 2003a; Orrman, 2003b; Rasila et al., 2003; Simonen, 1947, Soininen, 1961; Solantie, 2012; Voutilainen et al., 2020; Wilmi, 2003
2. Progressive regime (1722–1868)	Jutikkala, 1958; Heikinheimo, 1915; Huhtamaa and Helama, 2017; Jutikkala, 2003; Koponen and Saaritsa, 2019; Korhonen, 2003; Kotilainen and Rytteri, 2011; Kuisma, 1997; Kupiainen, 2007; Kylli, 2021; Metsähallitus, 2012; Mykrä, 2015; Niemelä, 2008; Niemelä, 2009; Rasila, 1961; Rasila et al., 2003; Simonen, 1947; Soininen, 1961; Soininen, 1974; Solantie, 2012; Tikkanen, 2019; Voutilainen, 2016; Voutilainen et al., 2020
3. Cattle regime (1869–1918)	Hjerppe, 1988; Heikinheimo, 1915; Huhtamaa and Helama, 2017; Häkkinen and Peltola, 2001; Jutikkala, 1958; Ihamuotila, 1979; Koponen and Saaritsa, 2019; Kotilainen and Rytteri, 2011; Kuisma, 1997; Niemelä, 2008; Niemelä, 2009; Ojala and Nummela, 2006; Peltonen, 2004a, 2004b; Peltonen, 2019; Rantatupa, 2004a; Rasila, 1961; Simonen, 1947; Vihola, 1991; Vihola, 2004a, Östman, 2004
4. Premodern regime (1919–1944)	Granberg, 1989; Hjerppe, 1988; Häkkinen and Peltola, 2001; Ihamuotila, 1979; Jutikkala, 1958; Koponen and Saaritsa, 2019; Kotilainen and Rytteri, 2011; Niemelä, 2008; Ojala and Nummela, 2006; Partanen, 2017; Peltonen, 2004a; Rantatupa, 2004b; Simonen, 1947; Vihola, 2004b
5. Modernisation regime (1945–1994)	Aakkula et al., 2006; Birge, 2017; Granberg, 1989; Granberg, 2004a, 2004b; Haapala, 2004; Hildén et al., 2012; Hjerppe, 1988; Häkkinen and Peltola, 2001; Jokinen, 1997; Kettunen, 1992; Kiander, 2001; Koistinen, 2009; Kola, 2002; Komiteanmietintiö, 1985; Komiteanmietintiö, 1987; Kuhmonen and Aaltonen, 1997; Kuhmonen and Niittykangas, 2008; Kuokkanen et al., 2017; Markkola, 2004; Muilu et al., 2016; Niemelä, 2004; Niemelä, 2008; Ojala and Nummela, 2006; Partanen, 2017; Raatikainen, 2018; Roiko-Jokela, 2004; Vepsäläinen, 2007; Vihinen, 2004; Waris, 1974; Ylivainio et al., 2015
6. Globalisation regime (1995–)	Aakkula et al., 2006; Aakkula and Leppänen, 2014; Ahokas et al., 2016; Arovuori, 2022; Arovuori and Karikallio, 2019; Berninger, 2018; Economydoctor, 2022; EU, 2020; Herzon et al., 2022, Hyvärinen, 2016; Jansik et al., 2021; Jokinen, 1997; Kaljonen, 2006; Kaljonen, 2011; Kaljonen et al., 2019; Kallio, 1997; Karhula et al., 2015; Karttunen et al., 2019; Kiander and Romppanen, 2005; Kivekäs et al., 2015; Koistinen, 2009; Kola, 2002; Koppelmäki et al., 2021; Kotilainen et al., 2010; Kuhmonen, 2018a, 2018b; Kuhmonen and Aaltonen, 1997; Kuhmonen et al., 2015; Kuhmonen and Siltaoja, 2022; Kuokkanen et al., 2017; Kuokkanen et al., 2018; Latvala et al., 2022; Kuosmanen et al., 2009; Lehikoinen, 2020; MAF, 2017; Markkola, 2004; Muilu et al., 2016; Niemi and Väre, 2019; Niskanen and Lehtonen, 2014; Ojala, 2006; Paloviita et al., 2017; Partanen, 2017; Parviainen and Helenius, 2020; Piipponen et al., 2018; Puupponen et al., 2022; Vainio, 2022; Valtioneuvosto, 2005; Vepsäläinen, 2007; Ylivainio et al., 2015; Yli-Viikari, 2019

system. The goal of the literature review was to produce 'data' to be used in the analysis described next. Table 1 summarises the literature used in the analysis per each regime.

The analysis proceeded in three stages. First, we identified the regimes and regime shifts on a coarse level. Second, we finetuned this initial understanding about the regimes by analysing the nature of the agrifood system in nine dimensions. Third, we analysed the temporal development of the regimes in terms of the adaptive cycle. In practice, the research process was iterative and moved back and forth between these stages: understanding about the dimensions of the systems as well as the phases of the adaptive cycle fed back to dating the regimes and regime shifts.

In the first stage, the aim of the analysis was to delineate the regime shifts, that is, those periods of time during which the system endured major changes, as well as the regimes that prevailed in between the regime shifts, during which the system developed on a specific path-dependent trajectory. The initial identification was based on narratives of a dominant idea configuring and delimiting the system dynamics within the agrifood system. While this step could only capture a coarse understanding of the system, it was necessary for building an initial framework about the timing of the regimes and the regime shifts in between.

In the second stage, we worked further with the initial regime framework to dive deeper into the dominant idea of each regime—in other words, this stage served to delineate the basin of attraction for each regime. This was done by analysing the nature of the system in nine dimensions. The dimensions included agricultural production, the main source of energy and nutrients, technology and production methods, food chains, culture and society, climate and environment, demography, international trade as well as agricultural and land use policies. Based on our reading of the historical literature, these dimensions captured the essential characteristics of the agrifood system in all times. These nine dimensions provided historical contexts and fitness landscapes for the regimes, as well as accounted for the structures, functions and processes of the system. This step also contributed to distinguishing between the consecutive regimes in more detail. Upon a regime shift, we expected to see changing contents in these dimensions. The detailed results of this analysis are given in Appendix A, which describes the dimensions of the system for each regime. For a brief presentation of the dimensions, see Table 2.

Third, the development of each regime was broken down into four phases of the adaptive cycle: reorganisation, exploitation, conservation and release. Identification of these phases was based on the indicators of system properties: resilience, connectedness and potential—as suggested in conceptualisations of adaptive cycles (Holling, 2001; Holling and Gunderson, 2002). During the adaptive cycle, *resilience* is at its lowest point in the late conservation phase, which makes a release phase more likely. In contrast, a similar amount of disturbance is less likely to make the system cross a threshold and collapse during the exploitation phase, where the resilience tends to be in its highest peak (Walker and Abel, 2002). Increasing complexity and *connectedness* within the system manifest a conservation phase, whereas in the release phase, these connections are broken to become rebuilt in the reorganisation phase. Source, contents and accumulation of *potential* are phase specific as well. The various forms of capital that become released in the release phase feed the exploitation phase. However, as some of the resources leak out of the system in the release phase (Holling and Gunderson, 2002), gaining resources from broader levels in the panarchy structure can be beneficial for the reorganisation process (Gunderson et al., 2002; Fath et al., 2015). There is also some empirical evidence suggesting that opportunities arising beyond the boundaries of the focal system may play a role in the process of reorganisation (Abel et al., 2006; Vang Rasmussen and Reenberg, 2012). The detailed results of this phase of analysis are presented in Appendix B, describing the systemic properties of each regime and phase of the adaptive cycle.

In addition to resilience, connectedness and potential, we also included two other indicators: type of the major feedback loops (reinforcing vs. balancing; Walker and Salt, 2006; Faulseit, 2016) and manifestations of agency (agency vs. structure; Archer, 2000; Lyon and Parkins, 2013). While these concepts are not the default analytical tools in studies of adaptive cycles within social-ecological systems, stabilisation of growth upon the turn of exploitation to conservation is connected with changing feedback patterns from self-reinforcing or amplifying feedbacks to stabilising or balancing feedbacks (Meadows, 2008; Fath et al., 2015). The growth in the exploitation phase is facilitated by self-reinforcing feedback loops, such as improved technology facilitating improved productivity, allowing again investments in technology. Balancing feedbacks dominate the conservation phase: ultimately, the consequences of growth may begin to 'eat away' at the prerequisites for growth—here the projected detrimental consequences of climate change to humanity perhaps serve as an extreme example.

Our rationale for including agency as an indicator of the adaptive cycle arises from the observation that the phase of adaptive cycle plays a role for exercising human agency (Westley et al., 2013). The findings of Lyon and Parkins (2013) on the relatedness of the adaptive cycle and the conceptualisation of cultural morphogenesis put forward by Margaret Archer (2000), among others, provide a signpost on analysing the comparative 'strength' of agency vs. structure in this setting. Lyon and Parkins argue that the adaptive cycle is a close match with the morphogenetic model, where actors are strongly bound by the structural constraints arising in the conservation phase, but through becoming aware of these constraints, they increasingly start to challenge them, and through reorganisation may contribute to transformation of the system. These ideas have not been widely adopted and tested in empirical research concerning adaptive cycles, but we see similarities in extant theorising of adaptive cycles especially in terms of the impacts of connectedness on the possibilities for (transformative) human agency. This is why we wanted to analyse the latitude for agrifood system actors to exercise their agency in the different phases of the adaptive cycle.

Table 2
Nine dimensions and five systemic properties underlying historical agrifood systems.

Dimension (D) or Property (P)	Description
D1. Agricultural production	Agricultural land use, main crops, new crops, self-sufficiency
D2. Main source of energy and nutrients	Types of energy and nutrient sources, local vs. external sources, new sources
D3. Technology and production methods	Main and new technologies in farming, evolution of mechanisation
D4. Food chains	Members of the food chain, evolution and structural change in the division of labour and markets
D5. Culture and society	Evolution of the nation state, settlement and employment structure, wars and societal reforms
D6. Climate and environment	Evolution of the climatic conditions, status of the environment and natural resources
D7. Demography	Pattern of population growth, farmers and landless people, migration
D8. International trade	Role and main patterns in imports and exports of agrifood products, trade balance
D9. Agricultural policies	Orientation and main measures of agricultural and land policies
P1. Resilience	Ability of a system to navigate the adaptive cycle, to tolerate disturbances, adapt and transform while retaining its essential functions
P2. Connectedness	Strength of internal connections and degree of internal control of a system
P3. Potential	Accumulated stock of various capitals (natural, economic, social, cultural) and capacities
P4. Feedback loops	Internal connections that control self-adaptation of a system contributing to either growth (self-reinforcing) or stability (balancing)
P5. Agency	Capacity of social actors to act intentionally, make deliberate choices and ultimately exercise power to affect social structures

4. Results: System dynamics of the Finnish agrifood system from 1334 to 2022

We identified six successive regimes from the 14th century to the present. The regimes can be conceptualised as multi-dimensional configurations of the agrifood system that are built around a few key attractors that condition the development of the social structure and organisation. The consecutive regimes are called the Expansion regime (1334–1721), the Progressive regime (1722–1868), the Cattle regime (1869–1918), the Premodern regime (1919–1944), the Modernisation regime (1945–1994) and the Globalisation regime (1995–). The regimes and main characteristics of their four phases (reorganisation, exploitation, conservation and release) are presented in Fig. 2 in the form of a continuously evolving adaptive cycle. In the following, the key features of each regime will be discussed.

4.1. Expansion regime: 1334–1721

The first cycle, the Expansion regime, was built on grain cultivation with varying degrees of self-sufficiency. It is considered to begin with a declaration by King Magnus IV of Sweden in 1334 and to last almost 400 years until 1721. The declaration stated that the uninhabited wilderness in the kingdom of Sweden, to which Finland belonged at the time, was to be colonised (Niemelä, 2008). This intent was promoted with exemption from taxes for the colonisers but had the ultimate aim of enlarging the tax base of the kingdom (Korpela, 2012; Huhtamaa and Helama, 2017). The following period was characterised by expansion of settlement further into the inlands (Simonen, 1947; Jutikkala, 1958; Soininen, 1961). Finland was inhabited by three geographically and culturally distinct populations. The western population practiced farming on permanent fields, the eastern population practiced mostly slash-and-burn agriculture and the Sámi people were hunters and gatherers. The Sámi people were slowly pushed towards the northern parts of the Scandinavian peninsula as the farming population spread out into their hunting lands.

Accordingly, the Finnish agrifood system during the Expansion regime was characterised by two distinct basins of attraction. (The hunter–gatherer system of the Sámi people should be considered a distinct system of its own, but as this study is focused on agrifood systems, it is not discussed in more detail here.) In the west, farming on permanent fields was based on fertilisation with cattle manure. The cattle foraged in the woods and meadows surrounding the villages, while the fields were reserved mainly for producing human food and horse feed, along with fibre plants needed for clothing (Nummela, 2003; Niemelä, 2008). The main role of the cattle was moving nutrients from the surrounding areas to the productive fields – for 1 ha of field, 3 ha of meadows were needed in terms of manure sufficiency (Korhonen, 2003). Animal protein was derived mostly from fish as cattle was malnourished in wintertime and only provided milk during the summer (Wilmi, 2003). Two varieties of grains – rye and barley – formed the backbone of the diets (Simonen, 1947; Wilmi, 2003; Niemelä, 2008).

The eastern system was based on slash-and-burn agriculture and the role of cattle was not as pronounced as in the west (Nummela, 2003; Orrman, 2003a; Niemelä, 2008). The nutrient economy in this system was based on releasing the nutrients bound to tree mass by fire. Once the burned land was utilised for a couple of harvests and some years of grazing, the trees were left to grow and reharvest the nutrients without further intervention. The slash-and-burn agricultural system was very productive and could sustain large families, but it also required a lot of labour force (Kuisma, 1997; Orrman, 2003a). The rotation times were very long, and the nature of the system was extremely expansive. It was also vulnerable to variation in weather conditions and could hardly sustain the population of the time. In fact, only the southern and western areas in Finland were self-sufficient in terms of bread grains (Orrman, 2003a). In other parts of the country, the livelihoods relied on a mixture of sustenance farming, hunting and fishing – especially fur animals were important trade items (Orrman, 2003a). In these areas the population also regularly relied on famine foods such as bread partly made of pine

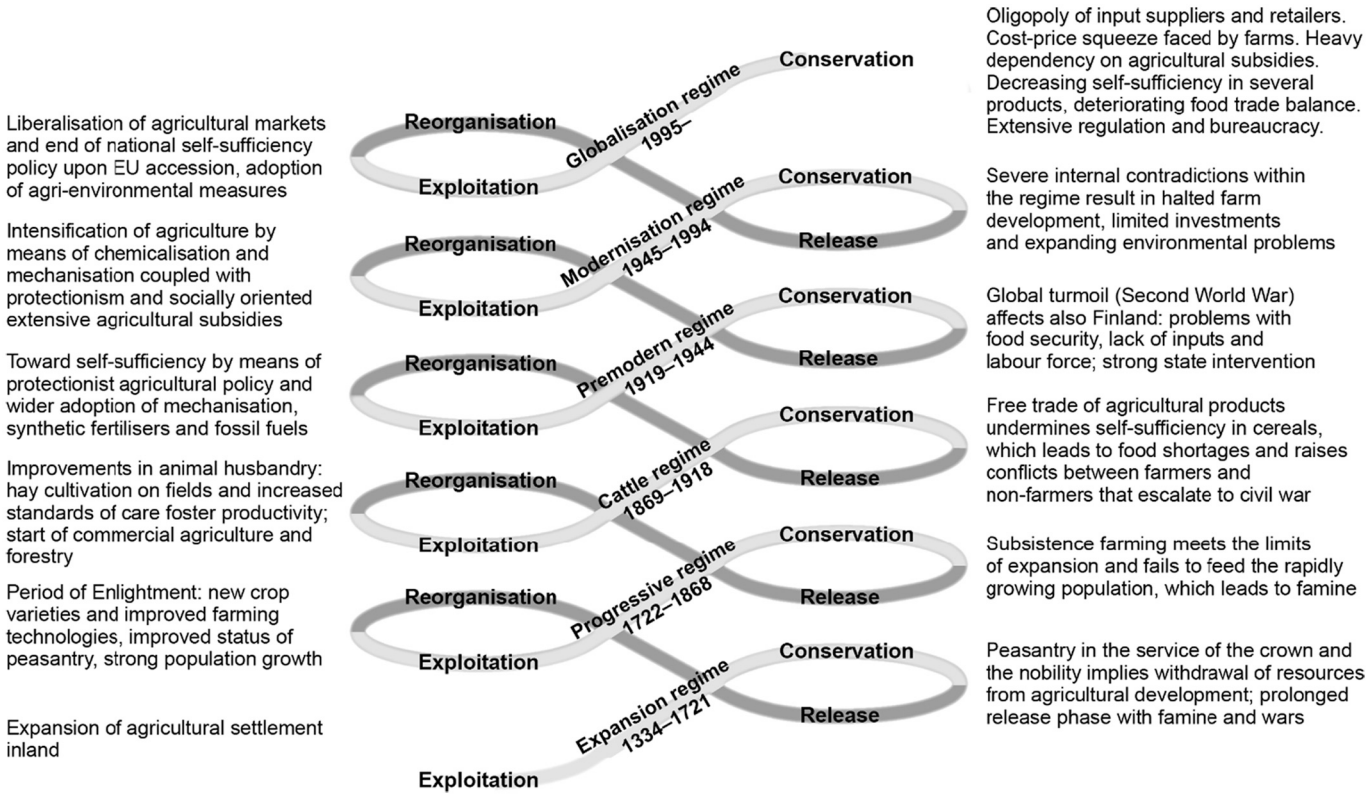

Fig. 2. Adaptive cycles in the Finnish agrifood system since the 14th century.

bark (Simonen, 1947; Orrman, 2003a; Kylli, 2021).

The exploitation phase of the Expansion regime was initiated by self-reinforcing feedback loops created by systemic potential, that is, abundant resources – available uncultivated land – together with population pressure and politics favouring colonisation (Jutikkala, 1958; Orrman, 2003a). This phase lasted until the 16th century. By then, the control of the state increased along with the power politics of King Gustav I to centralise state governance and to strengthen the kingdom's military rule (Jutikkala, 1958; Katajala, 2003; Niemelä, 2008). The web around peasant farmers tightened in relation to the crown (tax burden) and to the nobility (day labour), indicating increasing connectedness of the system and the beginning of the conservation phase. The consequences of these policies were harsh for the peasant farmers (Mäkelä-Alitalo, 2003; Korpela, 2012). Even though promotion of colonisation was continued, the strains imposed by heavy taxation, military service and numerous wars desolated farms and even some villages altogether (Simonen, 1947; Orrman, 2003b; Wilmi, 2003; Niemelä, 2008). The system was rigid, bureaucratic and control oriented (Lappalainen, 2021). The crown wanted farms to specialise in crop cultivation, and secondary or additional sources of livelihood – as important as they were – were not encouraged (Lappalainen, 2021). Growth-maintaining, self-reinforcing feedback loops based on expansionist policies were thus replaced by policies based on the deprivation of peasants, placing balancing feedback loops in the system. These hardships eventually culminated in a severe famine in 1695–1697, called the Great Death Years. The famine was triggered by extremely harsh weather conditions, called the Little Ice Age. This climatically unfavourable period lasted for several centuries (Huhtamaa and Helama, 2017 date the period to 1220–1650) and caused reoccurring harvest losses. During the Great Death Years, approximately 20%–30% of the Finnish population (originally half a million) was wiped out (Muroma, 1991; Voutilainen et al., 2020). Even though cold summers caused food shortages and famine all over northern Europe during this time, the destruction was most complete in Finland. During the Great Death Years, the inherent vulnerabilities of the Expansion regime, such as primitive farming technology, diets being built on only a few crops which were cultivated at the northernmost edge of their cultivation zone (Simonen, 1947; Solantie, 2012), materialised. By then, resilience of the system had declined in the conservation phase along with resources leaking to serve the crown and the nobility, coupled with a lack of secondary livelihoods. The remaining population was further burdened by continuing wars between Sweden and Russia until the early 18th century and thus prolonged the release phase of this cycle to last almost 30 years.

4.2. *Progressive regime: 1722–1868*

The peace between Sweden and Russia in 1721 meant that the easternmost parts of Finland were placed under the control of the Russian empire. The peace marked the possibility for the agrifood system to reorganise and finally embark on a new growth period. This regime is called the Progressive regime and it lasted almost 150 years until the late 19th century. The system had access to new system-external potential in the form of knowledge brought about by the Enlightenment (Niemelä, 2008), even though the basic nature of the agrifood system stayed untouched (Kylli, 2021) and thus the attraction basin was similar with the previous regime. This potential was translated into incremental improvements in the farming systems: new crop varieties (such as yellow turnip and potato), new farm animals (hens), new tools that allowed cultivation of heavier soils than before as well as developments in ditching and draining techniques (Simonen, 1947; Korhonen, 2003; Niemelä, 2008). The diffusion of knowledge and new innovations became possible through an increasing share of literate people and the establishment of university-level agricultural education during the late 18th century (Simonen, 1947; Niemelä, 2008). At the same time, the process of land parcelling enabled peasants to try out new farming methods on their own land, as peasants farming on common lands were tied by the opinion of the majority (Jutikkala, 1958; Saarenheimo, 2003). The 18th century was a climatically favourable period, and the population grew constantly in the exploitation phase of this cycle (Jutikkala, 2003; Voutilainen et al., 2020). This population growth pushed the government to legalise the establishment of crofts in the mid-18th century, which was earlier forbidden (although poorly supervised) so as to maintain large enough farms and a sufficient livelihood for the farm-based families (Kupiainen, 2007; Rasila, 1961). The establishment of crofts led to the expansion of farmed land, and the development of ploughing technologies led to the expansion of farmland to soils that were not cultivatable earlier (Niemelä, 2008). At the same time, the privileges of the nobility were abolished (Rasila, 1961; Niemelä, 2008). All these developments offered new opportunities for farmers and created self-reinforcing feedback loops that boosted the system's growth. From 1750 to 1850, the population quadrupled from 0.4 million to 1.6 million (Voutilainen et al., 2020).

In 1809, Finland became an autonomous part of the Russian empire, which marked the establishment of central state governance and, at the same time, the beginning of the conservation phase. Becoming part of Russia opened trade relations to the east in the form of butter exports and grain imports (Simonen, 1947). Butter exports allowed for the expansion of animal husbandry in the northern and eastern parts of the country and, at the same time, moved the emphasis of the population northwards and towards climatically less favourable areas (Solantie, 2012). The first agricultural organisations were founded in the 19th century both at the state and local level to develop farming methods (Niemelä, 2008). These were centrally managed and organised and did not lead to extensive grassroot involvement of farmers (Niemelä, 2008), which is also characteristic of the conservation phase.

The extensive farming style coupled with population growth gradually led to reaching the limits of the system. In the eastern areas, where slash-and-burn agriculture was practised, peasants started to complain about the decrease in forest base suitable for burning already in the mid-18th century (Jutikkala, 2003). The tragedy of the slash-and-burn technique was endogenous: it was so effective that it enabled significant population growth, which eventually made continuation of the whole system impossible due to its continuous demand of new areas to be burned. Thus, towards the end of this period, the eastern system based on slash-and-burn agriculture was gradually transformed into a farming system based on permanent fields (Saarenheimo, 2003; Niemelä, 2008). At the same time, the progression of land parcelling and the increasing value of timber made attitudes towards slash-and-burn more negative (Myllyntaus et al., 2002). In the western system, new fields were mostly cleared from meadows that had been previously used for feeding cattle (Wilmi, 2003; Saarenheimo, 2003). This led to reduced acreage for feeding the cattle and consequently to less manure, which was the key input for the whole agrifood system (Jutikkala, 2003; Niemelä, 2008). Towards the end of the period, the proportion of meadows to fields decreased from 3:1 to 2:1, implying severe scarcity of nutrients (Soininen, 1974; Jutikkala, 2003). Concomitantly, production capacity of grains stagnated while the population was becoming increasingly dependent upon them, resulting in a growing role for grain imports (Jutikkala, 2003). At the same time, finding a livelihood was difficult for landless people, who formed a significant part of the growing population (Voutilainen, 2016).

The vulnerabilities of the agrifood system were accentuated further when the availability of game animals no longer acted as a buffer for the fluctuations in crop yields. The eastern and northern populations were not self-sufficient in terms of bread grains but hunting and fur trading had provided important additional resources. Increasing population pressure, however, had led to overexploitation of numerous game and fur animals, as well as the persecution of large carnivores (Kunnas, 2018; Solantie, 2012; Tikkanen, 2019). In the 19th century, populations of species such as moose (*Alces alces*), deer (*Rangifer tarandus fennicus*), bear (*Ursus arctos*), wolves (*Canis lupus*), pine marten (*Martes martes*), squirrels (*Sqiurus vulgaris*) and whooper swans (*Cygnus cygnus*) declined

strongly, and some eventually went extinct (Metsähallitus, 2012; Mykrä, 2015; Tikkanen, 2019). Thus, strong balancing elements to the operative feedback loops were created in both the western and eastern systems when the limits of the local environmental carrying capacity were reached in terms of nutrients, the shrinking forest coverage and decrease in game animals as well as by the increasing amount of landless population. The resilience of the system was already weak, when extreme weather conditions caused harvest losses in the 1860s. The resulting Finnish famine, called the Great Hunger Years (1867–1868), was the last major famine in Europe killing 8% of the population (Voutilainen, 2016).

4.3. Cattle regime: 1869–1918

Within the historical literature on Finnish agriculture, the Great Hunger Years represent a threshold: a turn from "old agricultural model" towards a new one, based on new technologies, a reliance on cattle husbandry and the commercialisation of the agrifood system. The roots of these developments were manifold. Already during the Progressive regime in the 19th century, field grasses such as timothy and clover were introduced in Finland (Niemelä, 2008). They provided better yields than wild domestic grass species, but despite this, their adoption rate remained low until the end of the period. Farmers were initially reluctant to cultivate hay for the cattle on their best fields (Kuisma, 1997; Östman, 2004; Kylli, 2021). This changed dramatically after the Great Hunger Years and was strongly promoted by some agricultural experts of the time, who claimed that hunger in Finland would not end until cultivation of bread grains would cease once and for all (Simonen, 1947; Kuisma, 1997). The central innovation that formed the basin of attraction for the regime emerging after the famine in the late 19th century was cultivated grass for cattle feed, which enabled greater milk output of cows and paved the way to large-scale commercialisation of dairy production. This period is accordingly called the Cattle regime. This regime lasted about 50 years and was built on several developments forming self-reinforcing feedback loops. The key drivers were developments in ploughing technology and the processing of dairy products, the free trade of agricultural products and the rise of the forest industry, which were all related to the common development of industrialisation.

The Cattle regime is a good example of a socio-technical system, where the physical and social structuration of the system is anchored around specific technological solutions (Niemelä, 2008). The key technology in this system was the plough. Development in new plough technology was enabled by the improved availability and industrial-scale production of iron, which enabled adoption of grass as part of crop rotation on permanent fields instead of collecting hay from seminatural meadows (Östman, 2004). With the old-fashioned ploughs, terminating grass on permanent fields to give way to other crops was difficult and in itself prevented the adoption of grass as part of crop rotation. Another important technological innovation was a mowing machine that was suitable for harvesting grass from permanent fields, but not from seminatural meadows (Östman, 2004; Niemelä, 2008). Technological innovations were also introduced in the processing of dairy products, such as milk separators (Niemelä, 2008; Kylli, 2021).

Acquiring the new machines required financial resources from the farmers. Such resources were obtained by selling wood to the growing forest industry, as almost all farms owned forests (Simonen, 1947; Jutikkala, 1958; Niemelä, 2008). The emerging forest industry was thus an important source of system-external potential for the reorganisation of the agrifood system after the Great Hunger Years. The growth in the commercial value of timber meant the end of both slash-and-burn agriculture and the free grazing of cattle in woods, both considered destructive practices for forests (Heikinheimo, 1915). These two practices, coupled with the extensive demand for wood in construction and for energy, had resulted in large-scale destruction of mature forests in vast areas, especially in the southern parts of the country (Niemelä, 2008). Stronger differentiation between the agrifood system and the forestry system thus served the interests of both the emerging Cattle regime and the industrial forestry regime.

The new agricultural system was built around intensive animal husbandry and it expanded at an unprecedented speed. The number of cows doubled during the cattle regime (Simonen, 1947; Niemelä, 2008). Agricultural education and extension were institutionalised and became pivotal in spreading the technological innovations related to dairy farming (Vihola, 2004a). These developments contributed to the improved feeding and productivity of cattle – during the Cattle regime, the milk yield per cow more than doubled – which also encouraged farmers to take better care of their animals (Vihola, 2004a; Niemelä, 2008; Kylli, 2021). As a result, dairy products finally replaced manure as the primary output of cattle husbandry (Soininen, 1974).

At the same time, the global agrifood system was facing major changes. Cheap grain was flowing in from the new world (the US and Australia) and challenged the competitiveness of European bread grain production (Peltonen, 2019). This forced many European countries – including Finland – to seek new competitive advantage in animal husbandry and especially in dairy production. The import of grain was tax-free (Vihola, 2004a). In Finland this period is the first example of an agrifood system oriented towards the idea of comparative advantage in trade. However, the imported grains did not essentially challenge the subsistence farming of bread grains, but contributed to feeding the growing cities, industrial workers and landless people (Vihola, 2004a; Niemelä, 2008). The number of non-farm consumers had increased as a result of industrialisation: in 1910, 66% of employed people were farmers compared to almost 80% during the previous regime (Simonen, 1947; Ojala and Nummela, 2006). The building of the railway network and the growing importance of the monetary economy were integral for the growing role of grain imports in feeding the population (Vihola, 2004a). Finland exported butter but imported 60% of consumed bread grains and significant amounts of pork and eggs (Ihamuotila, 1979).

The exploitation phase of the Cattle regime was marked by various forms of self-organisation. The farmers established local agricultural organisations which were, unlike in the previous regime, controlled bottom-up (Jutikkala, 1958; Vihola, 2004a; Niemelä, 2008). Agricultural production and especially dairy production commercialised and self-organised into local cooperatives processing dairy products (Vihola, 2004a). Later on, centralisation increased throughout the agrifood system as it matured and marked the turning of exploitation phase into the conservation phase. This was manifested in the establishment of a central organisation within the central government (the agricultural administration *Maanviljelyshallitus* in 1892), among dairy cooperatives (the central cooperative Valio in 1905) and among farmers' organisations (farmers' union MTK in 1917), with the latter two remaining important actors in the field to this day.

The vulnerabilities of the Cattle regime related to the strategy of relying on the comparative advantage in the national food supply became apparent along with the growing global political instability that ultimately led to World War I. Due to this unrest, the global food trade started to flounder (Rantatupa, 2004). In 1917, Finland declared its independence from Russia. At the time, the domestic harvests were poor due to difficult weather conditions and grain imports from Russia stopped (Rantatupa, 2004; Niemelä, 2008). As a result, food shortages among the landless people emerged, intensifying the juxtaposition between the social classes (Häkkinen and Peltola, 2001; Rantatupa, 2004; Niemelä, 2008). Food shortages sparked conflicts that eventually led to the Civil War between land-owning farmers and landless people as well as industry workers in 1918. The release phase of the Cattle regime was chaos.

4.4. Premodern regime: 1919–1944

The Civil War left behind a deeply divided nation. Even though agricultural productivity had risen fast during the Cattle regime, the system had lost its resilience. The chosen free-market orientation in

agricultural policy entailed vulnerabilities that were related to fluctuations of food prices as well as varying availability of food products. These vulnerabilities had materialised during the global unrest. At the same time, the share of farmers in the population was decreasing due to emerging industrialisation, which meant that the interests of farmers and the interests of the growing consumer class had started to diverge.

In the reorganisation phase of the emerging regime, the young nation based its agricultural policy on the idea of self-sufficiency (Vihola, 2004b). During this regime, agricultural policies delivered social policy goals as much as they regulated food production. This was manifested, for example, in the case of crofters, as they became entitled to the land they farmed through redemption of their crofts. The basin of attraction for the Premodern regime formed around the promotion of self-sufficiency by means of small-scale farming and the clearing new fields, but also by mechanisation as well as the introduction of a completely new resource base: synthetic fertilisers and fossil energy.

Achieving self-sufficiency in food products was largely based on inputs that were, to a growing extent, imported from overseas: fertilisers, fuels, and, most importantly, animal feeds (Niemelä, 2008). Self-sufficiency was about achieving an equivalence between the food produced and food consumed, even though the agrifood system was paradoxically all but self-sufficient in terms of the inputs and the resource base that allowed such production. Synthetic fertilisers and fossil fuels had been introduced already during the Cattle regime but started to affect the composition of the system only during the Premodern regime. They served as the system-external resource that allowed the system to reorganise and grow after the release phase of the previous regime, accompanied by a 30% growth in the agricultural land (Niemelä, 2008). The exploitation phase of the Premodern regime was characterised by increased agricultural output – even to the extent of surpluses in the 1920s (Ihamuotila, 1979; Ojala and Nummela, 2006). Meeting the goal of self-sufficiency also required protectionism to prevent cheap imports of foodstuff from overseas. The bureaucratic apparatus to implement the policy objectives was based on customs duties, export subsidies, various kinds of regulations and finally agricultural subsidies (Ihamuotila, 1979). Surpluses of dairy products were significant in the 1930s and agricultural policies were initiated to regulate this development (Niemelä, 2008). These measures formed balancing feedback loops in the system and indicated the beginning of the conservation phase.

The Finnish economy and its agrifood system were strongly linked to the global economy, and despite the promising development witnessed during the Premodern regime, other kinds of development trajectories overseas affected Finland as well. The American economy was in a release phase in the 1930s, which triggered a global recession (Niemelä, 2008). The economic downturn hit especially hard on farmers who had invested and developed their farms and become indebted; many of these farms faced bankruptcies and forced sales (Rantatupa, 2004b; Niemelä, 2008). The system was recovering in the late 1930s, but the waves of the World War II struck Finland as well, and the country went to war with the Soviet Union in 1939. The war years in the 1940s (Winter War 1939–1940 and Continuation War 1941–1944) upset the system and caused a food shortage especially due to the limited supply of inputs, many of which had been imported, and by limiting the supply of labour and power: the men and the horses were away at war (Niemelä, 2008). The Finnish agrifood system was in crisis and the rather short (25 years) Premodern regime was in the release phase. Wartime policies succeeded in food rationing, however, and the population avoided full-scale famine.

4.5. Modernisation regime: 1945–1994

While the Premodern regime introduced the first steps towards a new fossil-fuelled metabolic basis for the agrifood system, this development was in full swing during the next cycle, which we call the Modernisation regime. The basin of attraction was organised around fossil fuels and nutrients together with the policy goal of maintaining the self-sufficiency of agricultural products (as during the Premodern regime) and embracing agricultural policy as a part of social policy through the aim of securing farmer incomes throughout the country and also on small farms. The reorganisation of the agrifood system after wartime was characterised by resettlement and strong striving for self-sufficiency. The peace treaty awarded half of the region of Karelia to the Soviet Union. The population coming from this area, representing 12% of the total population, was resettled all over Finland by splitting existing farms (Roiko-Jokela, 2004). Within a decade, 100,000 new farms (+50%) were established, 75,000 new houses were built, and a large amount of new farmland was cleared (Granberg, 2004b; Haapala, 2004; Roiko-Jokela, 2004). To encourage production and survival of farm livelihoods in all parts of the country, agricultural prices were regulated starting in the 1950s, and an extensive system of agricultural subsidies was introduced in the 1950s and 1960s (Kuhmonen and Aaltonen, 1997; Granberg, 1989, 2004a; Kola, 2002). Small farms and disadvantaged regions received additional subsidies (Kettunen, 1992). Food security improved and the population grew by 34% during the regime. Many new tractors and machines were sold to farms (the number of tractors on farms exceeded the number of horses in 1967; Waris, 1974), the use of chemical fertilisers was promoted even by subsidies ('agricultural billion'), and new crop varieties, animal breeds and farming techniques were adopted (Niemelä, 2004).

Strong growth in agricultural productivity was facilitated by the availability of system-external inputs in the form of nutrients and energy, enlarged farm and farmer populations, and the post-war reconstruction mentality, together with the adoption of production-oriented agricultural support policies and the progress of technology, mechanisation and chemicalisation of farming. The development pattern was the same as in other parts of the western world, relying on rapidly increasing productivity resulting from displacing human labour with financial capital in the form of synthetic inputs, fossil fuels and machinery. The application of chemical fertilisers released farming from the limitation set by the availability of manure, and applying pesticides allowed long monocultures, which reduced the need for fallowing, further promoting productivity growth (Aakkula et al., 2006; Niemelä, 2008; Kuokkanen et al., 2017). Productivity growth released large amounts of agricultural labour force to other sectors of society (Kuhmonen and Niittykangas, 2008). The development of technology boosted industrialisation, whereas the motorisation of the transportation system fuelled by fossil fuels promoted the centralisation and urbanisation of society. Productivity growth boosted specialisation throughout the food chain, as both production of inputs (energy and nutrients, machinery) and processing of products were peeled off from the farms to specialised processors and traders. Not only farms but also agricultural regions became specialised (north-eastern 'Cattle-Finland' and south-western 'Crop-Finland'), which reduced traditional mixed farming systems and ultimately meant a disconnection between cropping systems and animal farming systems (Granberg, 1989, 2004b; Markkola, 2004).

Following the growth of the agrifood system, already by the late 1960s the surpluses of several agricultural products had become established (Granberg, 2004b). An extensive system of policy measures to balance the food market was introduced: obligatory fallowing, slaughter and afforestation premiums, export subsidies, production quotas, establishment licences for animal units and so on (Komiteanmietintö, 1987; Kettunen, 1992; Kola, 2002). This restrictive balancing feedback marked the beginning of the conservation phase of the regime. Agricultural production was encouraged and restricted simultaneously with an extensive mix of policy measures. Upon the shift from the exploitation to the conservation phase, the number of farms, people employed in agriculture as well as food retail stores started to decrease (Koistinen, 2009; Granberg, 2004b; Muilu et al., 2016; Statistics Finland), which were all manifestations of the increasing centralisation throughout the agrifood system. At the same time, environmental problems started to become visible. Concerns about the excessive use of fertilisers causing eutrophication in both inland waters and the Baltic Sea emerged in the

1980s, while agriculture was later identified as the single most important cause of eutrophication (Jokinen, 1997; Aakkula et al., 2006; Ylivainio et al., 2015). The biological diversity of agricultural environments impoverished along with the intensification development (Vepsäläinen, 2007), which was not, however, a major public concern during this period. The decline took place especially through the discarding of meadows and traditional rural biotopes that used to play a major role in both feeding cattle and collecting hay during the Expansion and Progressive regimes (Birge, 2017; Raatikainen, 2018).

The conservation phase of the modernisation regime has been considered a 'period of helplessness' (Kuhmonen and Niittykangas, 2008, 27), as the internal connectedness increased alongside the consecutive introduction of new measures, which created new lock-ins and contradictions. For example, in the 1970s and 1980s about one half of the agricultural budget was used for encouraging production and about one third for cutting off production and for subsidised exports of the surpluses (Komiteanmietintiö, 1985). Incentives for farmers were mixed and farm development was halted due to restrictions. Agricultural investments had been in steady decline since the early 1980s, and from 1991 to 1994 as much as 22%–23% of the farmland lay fallow (Statistics Finland). Rapid industrialisation, urbanisation and post-industrialisation, which manifested in the development of a service economy, had emptied rural areas throughout the country (Vihinen, 2004). The regime was in a dead-end stage in terms of economy, ecology, markets and public spending, when it faced the consequences of the disintegration of the Soviet Union.

The disintegration of the Soviet Union in 1991 destroyed important trade relations. Along with the collapse of overheated financial markets, Finland was thrown into a severe economic recession lasting from 1990 to 1993, during which the GDP dropped by 13% (Statistics Finland). Even though the origins of this crisis were not related to the food system, the resilience of the food system was affected as the regime approached the release phase. Over 100,000 Finns reported hunger, and 'bread lines' made a return after decades of mounting welfare (Kiander, 2001). In the aftermath of this turmoil, Finns voted for EU membership in 1994. The expectation of EU membership set in motion the release phase of the Modernisation regime, as many policy instruments were abandoned or transformed to comply with the regulations of the EU (Kuhmonen and Aaltonen, 1997; Markkola, 2004). The Modernisation regime in Finland lasted almost 50 years, until 1994.

4.6. Globalisation regime: 1995 onwards

Finland's accession to the EU on 1 January 1995 initiated the Globalisation regime, which to date has lasted over 25 years. While the metabolic basis for this regime is built, as it was during the previous regime, on fossil fuels, on the policy level the system's basin of attraction relies, contrary to the previous regime, on the free trade of agricultural products within the European Union and selectively across its bordersas well as on the aim of retaining a fair self-sufficiency in food at the EU level rather than on the national level (Kuhmonen and Aaltonen, 1997). These goals are accompanied by objectives related to environmental sustainability and climate change mitigation, the role of which has grown stronger throughout the regime (Kuhmonen, 2018a; EU, 2020). Attaining these goals simultaneously requires extensive agricultural subsidies; without these subsidies the production would move away from less favourable areas, the Union's food sovereignty would decrease, and the environmental burden of agricultural production would increase.

The reorganisation of the Globalisation regime took place through the abandonment of the extensive national policy measures – which were favourable to small farms and disadvantaged regions – and the adoption of the measures of the Common Agricultural Policy (CAP). As a result, farm gate prices (the prices farmers receive from their products) were cut by about 40% overnight (Kiander and Romppanen, 2005). The transition period from 1995 to 1999 to level out the national subsidies and some remaining nationally funded long-term subsidies for northern agriculture alleviated the economic losses for farmers, however (Markkola, 2004). The transition period corresponds with the growth phase of the Globalisation regime. The growth of the system was based on farmers' changing investment behaviours – investments doubled during this period (Hyvärinen, 2016). Finnish farmers were introduced to a wide array of new subsidy schemes, such as the organic farming scheme that rapidly found a foothold within the Finnish agrifood system. CAP funds thus acted as the system-external potential that enabled the growth of the system.

Farm investments were boosted by both stick and carrot: farms had to grow in order to provide a living for the farm families, while the subsidy system also provided incentives for investments. Growth resulted in increasing productivity, specialisation and centralisation, from which the food industry and retail trade have greatly benefitted. The share of food processing and retail trade in consumer food expenses has grown at the cost of primary production (Kuosmanen et al., 2009; Kotilainen et al., 2010; Piipponen et al., 2018). From the beginning of the Globalisation regime, average farm size has grown from 22 to 51 ha (Natural Resources Institute Finland, 2022), while the number of farms has decreased by 55% (Natural Resources Institute Finland, 2022). The growth of farm size has been especially strong in animal husbandry (Economydoctor, 2022). At the same time, despite increasing farm size and productivity, the profitability of farming has been in constant decline throughout the whole period (average profitability ratio 0.55 in 2000–2007 and 0.40 in 2008–2019; full compensation for labour and capital in 1.0; Economydoctor, 2022), which manifests as an unescapable cost–price squeeze at the farmgate. Securing farm income through scale economies has been the standard solution to the decreasing prices of agricultural products, which has strengthened the trend of regional specialisation of production that started already during the Modernisation regime.

Despite the continuing trend of increasing productivity at the farm level, the growth phase of the Globalisation regime did not last long, and the system moved into the conservation phase already around the year 2000. During the conservation phase, centralisation and complexity within the system have increased, which can be observed through several balancing feedback loops limiting the growth of the system. These balancing feedbacks are observable as conflicting aims of system actors and trade-offs that create rigidity and unintended consequences through the system dynamics. For example, the redirection of agricultural support upon EU accession from production subsidies to area-based payments to counteract the productivist tendencies entailed two major consequences. First, by subsidising ownership of resources (farmland and animals), it resulted in elevated prices of agricultural land. This trend has contributed to the increasing debt burden of developing farms (MAF, 2017) and the difficulties of enlarging farmers to acquire new farmland especially in areas specialised in cattle husbandry, which the farmers have counteracted through clearing new fields from forests (Niskanen and Lehtonen, 2014; Huttunen, 2015) – a practice considered detrimental for both climate targets and nutrient leakages. Second, the new incentive logic, which made farmers subject to external control and on-spot checks, caused a cultural clash in terms of the basic ideology of farming between agricultural administration and farmers: whether it is about producing food or following subsidy prescriptions (Kaljonen, 2006). Despite the continuous attempts to decrease the bureaucratic burden related to agriculture, the complexity and multiplicity of agricultural policy objectives (some of which conflict with each other) have increased to the extent where simplification has itself become a policy objective (Kuhmonen, 2018a, 2018b).

The CAP sets significant environmental objectives that aim at controlling the negative externalities caused by agricultural production as well as at strengthening the public goods provided by agriculture, which are both enforced through prescriptions related to subsidy measures. Over the course of more than 25 years of membership, agriculture's negative externalities, especially those related to nutrient-loading

potential, have indeed diminished (Natural Resources Institute Finland, 2016), but reduced pollution potential only slowly translates into observable changes in water quality, and at the same time, climate change increases runoffs and thus counteracts these efforts (Aakkula and Leppänen, 2014). The CAP, however, is not a very effective tool in intervening in issues such as recycling nutrients throughout the food system or disengaging from the use of fossil inputs. The overarching trends of specialisation and centralisation of production are difficult to counteract through the measures offered by agri-environmental schemes, and thus the measures can, at best, only slow down the negative environmental developments such as declining agricultural biodiversity or dwindling carbon content in the soil (Herzon et al., 2022; Yli-Viikari, 2019). For these reasons, the agri-environmental policies are considered to have failed to meet their environmental targets (Kaljonen, 2011; Kuokkanen et al., 2018). These failures stem from the difficulty to resist the path-dependency of the contemporary regime (see Kuokkanen et al., 2017) with policy tools that are themselves an integral part of the regime.

While the Finnish agrifood system is still fairly self-sufficient in many products, the self-sufficiency rates have been in constant decline in several products, especially meat (Statistics Finland), and the diversity of domestic food production has decreased (Lehikoinen, 2020). The trade balance of agricultural and food products is negative and has been in a linear decline since accession to the EU: about −0.5 billion euros in 1995, −1 billion euros in 1998, −2 billion euros in 2008, and − 3 billion euros in 2017 (Niemi and Väre, 2019). The increasing concentration throughout the agrifood system has created oligopolistic markets, where the ownership of the input suppliers, food processors and wholesale trade has become more centralised and partly transferred to international operators and the power of trade has strengthened in relation to other actors (Muilu et al., 2016; Paloviita et al., 2017; Arovuori, 2022). Sanctions placed upon Russia in 2014 by the EU stopped eastern dairy exports and have ever since put further downward pressure on the prices of dairy products. Due to the tightening financial situation on farms, the increasing bureaucratic burden and the heated societal debate on the negative environmental impacts of farming and especially animal husbandry (Karhula et al., 2015; Puupponen et al., 2022), there are signs of an increasing abundance of mental health problems among farmers (Kivekäs et al., 2015). The Finnish agrifood system is very reliant on imported inputs (Lehikoinen, 2020; Jansik et al., 2021), especially fertilisers, the price of which has skyrocketed since the war in Ukraine started in 2022 (Latvala et al., 2022). The pressures for a fundamental reorientation of the agrifood system are increasing. The production-oriented approach of confronting sustainability problems as questions of agri-environmental management no longer suffices, and the scope of animal production and the need for a transition towards plant-based diets is under heated debate (Kaljonen et al., 2019). Yet geographically inclusive visions of alternative pathways for the system to embark on are scarce (Kuhmonen and Siltaoja, 2022).

5. Discussion

In this study, we set out to explore the long-term evolution and transition dynamics within the Finnish agrifood system. Through identifying the historical regime shifts, we aimed for our findings to increase understanding on the prerequisites for transformation and thus to help navigate the prospective sustainability transition in the agrifood system in Finland and possibly also in other contexts. By utilising the adaptive cycle as the organising theory for our analysis, we were able to trace the origins of the cyclical evolution pattern of the agrifood system and the recurring sustainability problems and crises. Specifically, we observed that sustainability problems were related to the very nature of the regimes: in essence, the attractors upon which they were built. The immanent stages of the cycle therefore provided a firm causal texture for the cyclical behaviour of the agrifood system.

Our analysis indicates that regime shifts in the Finnish agrifood system have occurred when the low resilience of the system in the late conservation phase has coincided with an external disturbance: extreme weather conditions, wars and an economic recession. The system had been exposed to such disturbances in other stages of its evolution, but for a disturbance to cause a system-wide collapse, the overall resilience of the system had to be low. For example, while the Little Ice Age caused reoccurring harvest losses throughout the country during the Expansion regime, a system-wide collapse was only triggered when the bad weather conditions coincided with the internal vulnerability of the system. However, not all of the regime shifts were transformative in terms of switching the attractors upon which the system was built. For example, the Expansion and Progressive regimes were built on rather similar attractors as were the Premodern and Modernisation regimes. However, the system never returned to same organisation or structure as before—the fitness landscape and the basin of attraction changed in all of the regime shifts observed here. As such, the 'transformability' of the regime shifts varied along a continuum rather than along a clear-cut incremental/radical duality.

When radical transformations within the Finnish agrifood system did take place, they required changes in the system's socio-metabolism (see also Fischer-Kowalski, 2011; Haberl et al., 2011). Such metabolic changes could be dated to the turn from the Progressive regime to the Cattle regime, where the system shifted from a meadow–field and slash-and-burn agriculture to field-based production, and to the transition from the Cattle regime to the Premodern regime, where the agrarian model transformed to an industrial one (Pichler et al., 2017). The shift from agrarian to industrial model could be depicted as a shift from the era of scarcity to the era of abundance. Upon this shift, the resource use changed from extensive and decentralised to intensive and centralised. During the era of scarcity, the inputs were mostly internal to the system. Livelihoods and nutrition relied on the surrounding nature and its resources. Relatedly, population growth implied increasing pressure on the local natural resources which could be observed in several developments especially in the 19th century: destruction of forests and extinction or near-extinction of several animal species, especially macro fauna. The era of scarcity prevailed until the mainstreaming of fertilisers, pesticides and energy, which were brought to the agrifood system from external sources. This change of socio-metabolism made it possible to decouple food production from the limitation set by the natural capacity of the system based on soil productivity and the availability of manure. When livelihoods and nutrition were released from the limits set by the local resource base, some of the pressures for exploiting them were also released (e.g., the need to clear more fields) – yet at the same time giving rise to new kinds of problems brought about by the adoption of fossil and synthetic inputs, such as overproduction and waste issues (including climate change, eutrophication and other forms of pollution).

Growth and its maintenance have been central questions for the Finnish agrifood system throughout the history of 700 years explored here. Not only has the population grown, but so has welfare and material consumption—exponentially so during the last 100 years. The growth orientation bears important implications for the observed system dynamics. The reorganisation taking place after the release phase can be based on existing resources—those that are released in the systemic collapse—but as, for example, Gunderson et al. (2002) and Fath et al. (2015) note, importing resources from broader scales in the panarchy structure may help, especially as some of the released resources tend to leak out from the system during the release phase. Our results imply that such activation energy has played a role in facilitating reorganisation towards a new growth phase. Such activation energy—originating either from higher hierarchical levels in the panarchy structure or from adjacent systems—has enabled reaching a growth track within the agrifood system. They have taken the form of knowledge and innovations originating elsewhere in Europe (Progressive regime), the commercial value of forests allowing investments in iron tools and farm machinery (Cattle regime), imported synthetic fertilisers and fossil fuels (Premodern and Modernisation regimes) and EU subsidies (Globalisation regime). At the

same time, the source of new potential is decisive for forming the basin of attraction that starts to define the development of the emerging regime, and later on contribute to the path-dependency of the established regime.

As well as igniting growth, the maintenance of growth tends to be the objective for system management and interventions – growth brings new opportunities to exploit, it is usually related to peaceful times, and growing systems tend not to collapse (Walker and Salt, 2006). At the same time, growth brings a system closer to its boundaries, which will eventually limit its growth by turning some of the positive, self-reinforcing feedback into negative, balancing feedback. These developments can be observed as sustainability problems that have accompanied the Finnish agrifood system throughout its history. Essentially, in the course of each regime's maturation, things that were initially desirable became detrimental from the viewpoint of the regime's sustainability. These included expansion of population and farmland during the Expansion and Progressive regimes (which contributed to growing the tax base but eventually led to reaching the carrying capacity of the system), reliance on comparative advantage in foreign trade during the Cattle regime (which allowed technological development and productivity growth within the sector but eventually created food shortage when the global trade channels choked up), reliance on the external inputs during the Premodern regime (that allowed productivity growth but led to food shortage during the war years) and reliance on protectionism, regulation and subsidies during the Modernisation regime (that secured both productivity and farmer incomes but blocked innovations and structural development as well as caused environmental damage).

Specialisation, centralisation, connectedness, regulation and complexity tended to increase within all six regimes along with their maturation. This implied that more system resources were needed for maintenance and legitimacy of the system (see also Renfrew, 1984; Faulseit, 2016). The growing rigidity and escalating sustainability problems observable during the conservation phase make a system vulnerable to external disturbances and lead to the loss of resilience. When an external disturbance such as a war, economic recession and harsh weather conditions coincides with an internal vulnerability such as tax deprivation, shortage of nutrients, overexploitation of natural resources or extensive dependence on global trade, the agrifood system crosses a critical threshold and dives into a release phase (see also Tubi, 2020). All the release phases during the history of the Finnish agrifood system observed here have taken place as a result of the system losing its resilience, the manifestations of this extending from the emergence of food help, with 100,000 Finns reporting hunger in the transition from the Modernisation regime to the Globalisation regime, to large-scale, deadly famines killing 20% to 30% of the population, as in the shift from the Expansion regime to the Progressive regime.

Despite the destructive nature of the crises, they were critical in opening up the window of opportunity for the transformation of the system (Young, 2010; Herrfahrdt-Pähle et al., 2020): the emergence of a new set of attractors and a regime shift. In other words, no regime shifts took place without crises. The elements of the newly emerging regime often originated from the sustainability problems of the dominant regime, which paved the way to discursive contests about the direction of the future developments. Interestingly, when the basin of attraction of the system changed profoundly, the new regime took an opposite direction from the old one in terms of trade orientation: from free trade to protectionism in the shift from the Cattle to the Premodern regime, and from protectionism to (EU-free) trade in the shift from Modernisation to Globalisation. The agency of actors determined to take the system in a new direction played a key role during the reorganisation phase. The role of single decisions and single decision-makers was also pronounced during the release phase, as it is these decisions that could determine whether the system was heading towards full-scale chaos or a milder disturbance (Fath et al., 2015).

Predating most of the radical transformations, the ingredients for the emerging regimes had already existed during the previous regime, but were unable to break through due to systemic rigidities. These rigidities of the conservation phase decrease the actors' room to manoeuvre and weaken their opportunities to manage the mounting sustainability problems. For example, despite the strong sense of a dead-end that was observable at the end of the Modernisation regime, the system actors were unable to deliberately lead the system towards transformation. The fight to keep the system in the conservation phase despite clear signs of weakening resilience can be detrimental for the outcomes when the system finally collapses. On the other hand, the resilience theory argues that allowing the adaptive cycle to play out at smaller scales of the panarchy can promote the resilience of the system at larger scales. Observations from the farm system level in Finland—the most critical subsystems for the resilience of the whole agrifood system—suggest that the renewal and transformation of farm systems is currently strongly constrained, which increases the vulnerability of the whole agrifood system.

The sustainability problems are the consequence of the open nature of complex systems such as agrifood systems: there is no one 'perfect' and conflict-free solution for the organisation of the system (Holling and Gunderson, 2002; Folke, 2006). The sustainability transition currently sought for implies a radical change in the metabolic basis of the agrifood system through a shift from fossil inputs to renewables. Such a transformation is likely to affect the resilience of the system as well. The contemporary constellation of the agrifood system – the Globalisation regime – is in the conservation phase: the system displays various signs of rigidity and lock-in, the system structure significantly limits actors' room to manoeuvre, the pressures for a radical transformation are mounting and the discursive contests about the future direction are becoming heated. To date, the current regime has proved to be resilient to shocks such as the Covid-19 pandemic (Meuwissen et al., 2021). However, the system is also approaching the carrying capacity of the Earth system especially in terms of multiple planetary boundaries (Steffen et al., 2015), which accentuates the need for systemic change. In the light of our analysis, it is not likely that such a change can be achieved without a crisis. One potential such crisis is currently gaining strength in the form of the Russian invasion of Ukraine and its consequences, which are being seen in the shortage of fossil energy and nutrients as well as the looming food crisis due to the cessation of food exports from Ukraine.

The results of this study make several calls for further research as well as highlight questions of relevance in the practical sphere of agrifood policies. First, we argue that in order to navigate the developments arising after the Globalisation regime, we need alternative visions about the elements of the regime, specifying the 'sustainability' of the sustainability transition sought for (Feola, 2020; Jensen, 2012; Meadowcroft, 2011), as well as delineating the pathways needed to attain such visions. Throughout the history of the Finnish agrifood system, both population growth and economic growth have led to reaching the limits of the system's carrying capacity. Objectives, policies and practices targeted at growth need critical scrutiny and alternative frameworks that are not centred around growth, since in the past the elements and drivers of growth have been the seeds of the sustainability and resilience crisis. It would be of utmost importance to explore the compatibility of post-growth and degrowth scenarios with the resilience theory, as it is the very growth that is a central part of the system dynamics but that also takes the system closer to collapse. The paradoxical finding about the impetus for a system's growth turning into seeds of destruction at the conservation phase also requires further research from different geographical contexts and different systems. Second, our results call for attention to strategies that build resilience, adaptive capacity and food security for both good times (as in the front loop of the adaptive cycle) and bad times (as in the back loop). Allowing the system to regenerate from within is a prerequisite for resilience. Developing policies for a post-fossil future and letting the farm systems transform accordingly instead of collapse would build resilience for the emerging regime

within the Finnish agrifood system. Third, we also point to the most obvious limitation of this study and suggest that quantifying the mostly qualitative findings of this study would shed more light on the system dynamics observed here.

6. Conclusions

In this study, we set out to explore the historical regime shifts that have taken place in the Finnish agrifood system from the 14th century to the present day by utilising adaptive cycles as the analytical device. The adaptive cycle accommodates the idea of changing stability domains within a social-ecological system, which can be conceptualised as regimes: the temporally stable modes of organisation of a system, organised around a set of (changing) attractors. We found that it is these very attractors that gave rise to the growth of the system, associated with the growth of both human population and agricultural production—and eventually, to its collapse. While growth tended to be a central goal for those managing the system, it also created unintended and unwanted consequences, such as rigidity and centralisation of resources into the hands of the few, as well as environmental problems ranging from resource depletion and loss of biodiversity to different forms of pollution, such as climate change and eutrophication. These unintended consequences weakened the system's resilience and made it prone to disturbances, such as extreme weathers, wars and economic recessions. The vulnerabilities originate from the same source as the system's growth: geographical expansion, (over)exploitation of local resources and reliance on externally sourced food products or inputs. After collapse following the materialisation of these vulnerabilities, the Finnish agrifood system has reoriented towards more or less different pathways. Changes in the system's energy and nutrient metabolism have implied more fundamental regime shifts than those related to changes in the policy orientation or introduction of new innovations of more incremental nature. Thus, while the release of the contemporary mode of organisation can have detrimental consequences for the system's capacity to deliver on its central function—feeding the people reliant on it—it opens up the window of opportunity for systemic renewal.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Central dimensions of the agrifood regimes in Finland

Dimension	Expansion regime (1334–1721)	Progressive regime (1722–1868)	Cattle regime (1869–1918)	Premodern regime (1919–1944)	Modernisation regime (1945–1994)	Globalisation regime (1995–)
Agricultural production	Main crops: barley and rye. Introduced: oats, buckwheat, beans, peas. Animal protein mainly from fish and dairy products, in smaller amounts meat from livestock and game. Famine foods are widely used (except for the best farming areas).	Increasing acreage. Main crop: rye. Expanding: oats. Introduced: yellow turnip, hemp, hens, potato, red clover, field grass. Famine foods are widely used (except for the best farming areas).	Increasing field acreage, two-thirds of which is used for fodder production. A very rapid growth of animal husbandry. Growing productivity of cattle: milk yield per cow doubles. Self-sufficiency in many products is declining, e.g. self-sufficiency in bread grains is 35%–40% in the early 1910s. Half of the cereals is rye. Increasing importance of potato. Introduced: sugar beet.	Increase in productivity and in cultivated acreage. Overproduction of some products. Increasing self-sufficiency in bread grains: from 60% to 90%. Milk remains important: half of the sales income in agriculture.	Increased productivity. Growth in the production of barley (becomes more popular than rye from 1951 and more popular than oats from 1977), pork and poultry. Decreasing grass area since 1958: more than 50% of the field area in the 1950s, 30% in the 1960s. Transition from horses to tractors releases 0.5 million hectares horse feed area. Gradual mounting of structural surpluses in several products.	Decreasing number of farms and increasing farm size. Production remains regionally specialised. Growth in the production of poultry continues. Growth of organic farming (2% of the field area in 1995, 14% in 2019).
Main source of energy and nutrients	Human and animal labour, wood; emerging local water and wind power. Naturally occurring nutrients from the meadows and forests are harvested with cattle (manure) or fire.	Human and animal labour, wood, local water and wind power. Naturally occurring nutrients from the meadows and forests are harvested with cattle (manure) or fire.	Human and animal labour, wood, local water and wind power, introduction of fossil fuels. Clover establishes and allows fixing nitrogen from the air. Introduction of synthetic fertilisers, but manure remains important.	Human and animal labour, wood, local water and wind power, fossil fuels, expansion of electricity network. Synthetic fertilisers, nitrogen fixing plants, fossil fuels, manure.	Electricity, fossil fuels, wood. Synthetic fertilisers, nitrogen fixing plants, manure.	Electricity, fossil fuels, wood; emerging heat pumps, local solar and wind power. Synthetic fertilisers, nitrogen fixing plants, manure, introduction of recycled fertilisers.
Technology and production methods	East: slash-and-burn. West: permanent fields, cattle; rotational farming (2 crops),	In the east slash-and-burn with shortening rotation times. In the west, meadow–field ratio	Lack of meadows was resolved by producing cattle fodder on fields instead of meadows, which was possible due	Regional specialisation of production: bread grains in the west and fodder elsewhere.	Deepening of regional specialisation of production. Adoption of agri-industrial model	Improved fertilisation practices. Large animal units after removal of restrictions: milking robots, automation.

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Dimension	Expansion regime (1334–1721)	Progressive regime (1722–1868)	Cattle regime (1869–1918)	Premodern regime (1919–1944)	Modernisation regime (1945–1994)	Globalisation regime (1995–)
	meadow–field ratio 3:1. Watermills and windmills for grinding grain in the west.	diminished from 3:1 to 2:1 (implies a lack of manure in southern Finland). Cattle fodder almost solely from meadows. Rotational farming (2–3 crops). Developments in ploughing technique allow cultivation of grass and heavy soils. Developments in ditching and draining.	to improved iron tools. End of slash-and-burn. Technological innovations in the processing of dairy products.	Early mechanisation: land engines, first tractors.	through intensification of production on all fronts: new crop varieties and breeds, synthetic fertilisers, herbicides and pesticides (resulting in fallowed fields to be less than 100,000 ha in 1950–1985), improved drainage, intensified tilling. Overfertilisation is established as a practice due to the history of a constant lack of nutrients. Decoupling of production and land capacity through external inputs. Expansion and development of tractors, harvesters and farm machinery.	
Food chains	In the best farming areas (south and west) subsistence farming, in other areas primitive exchange economy (especially furs). Grain forms the backbone of diets.	Subsistence farming, also exchange economy in the east and north. The limits of the local environment's carrying capacity are approaching with the current technology, which accentuates in the Hunger Years 1867–1868.	Commercialisation of agriculture, foundation of agricultural cooperatives. Reliance on comparative advantage in animal husbandry while importing grains. Increasing prices of agricultural products.	Recession in the 1930s hits especially developing farms. Increasing food prices. Self-sufficiency by the end of the period in terms of many products but not in terms of inputs.	Activities are divested of the farms to the specialised input industry and food industry. Expansion of domestic input and machine industry. Increased division of labour. Drastic decrease in the share of agricultural employment and GDP. Number of production, processing and trade units starts to decrease since the 1960s.	Number of production, processing and trade units decreases further. Strong centralisation in both ends of the food chain. Profitability of agriculture is in steady decline in the 2010s.
Culture and society	Living in villages, farming on common fields (west). Reformation of the church. Finland is part of Sweden. Centralisation of power to the King. Wars during the 1600s.	Change from densely populated villages to unified farms along with the Great Partition from 1750s onwards. Share of literate population increases, which enables agricultural extension and education. Weakening status of the nobility. From Swedish to Russian control in 1809.	Formation of agricultural organisations and cooperatives. Emerging industrialisation alleviates the situation of landless people and increases the importance of monetary economics. About two-thirds of population gains their livelihood from farming. Building of railway network. Economic recession in 1910s due to global unrest. Independence from Russia in 1917. Growing inequality between social classes escalates into the Civil War in 1918.	Strengthening of the national identity. Crofters become entitled to claim the land they farm. About 60–70% of population still gains their livelihood from farming. Global economic recession in 1929–1934 due to overheating of both agricultural and industrial markets. World War II spreads to Finland: Three interrelated wars in 1939–1945.	Reconstruction and war compensations as a national project. Establishment of 100,000 new farms for war refugees. The share of farm employment diminishes from 50% to 8%. Building of the welfare state. Urbanisation depopulates rural areas. From agrarian to industrial and from industrial to post-industrial service economy. A serious economic recession in 1990–1993 as the result of an overheated economy and collapse of trade with the Soviet Union.	Rising environmental awareness and sustainability concerns. Consumers are becoming increasingly detached from food production. Digitalisation and web-based interaction; rise of social media. The share of farm employment continues to decrease and is less than 3% in 2018.
Climate and environment	'Little Ice Age' 1450–1850. Yield losses on a regular basis. Local timber shortages due to slash-and-burn agriculture and cattle foraging.	Unfavourable climatic period continues. Vast destruction of mature forests, local timber shortages. Many game animal populations and	Strong decline of meadows and expansion of fields. Declined stocks of game animals; some species have disappeared. Better climatic conditions until the 1910s.	Meadows cleared to fields, grazing cattle in the forests decreases due to the rising value of forests and changes in the production system.	Eutrophication of surface waters due to excessive nutrient application and drainage of peatlands. Intensive application of pesticides. Declining biodiversity	Accelerating climate change due to the use of fossil fuels. Application of fertilisers and pesticides becomes controlled. Continued decline of biodiversity of agricultural areas due to

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Dimension	Expansion regime (1334–1721)	Progressive regime (1722–1868)	Cattle regime (1869–1918)	Premodern regime (1919–1944)	Modernisation regime (1945–1994)	Globalisation regime (1995–)
		large carnivores decline or go extinct.		Favourable climatic period in the 1930s.	of agricultural areas due to disappearing meadows and pastures. Growth of game animal populations.	decreasing grazing of cattle. Problems with soil quality.
Demography	Slow but fluctuating population growth, expansion of settlements into new areas. Population pressure especially in the slash-and-burn areas. Crop failures and small-scale famines are common but worst in the Great Death Years 1695–1696 (25%–30% dies).	Accelerating population growth (quadruples in 1750–1850) and regional expansion of the settlement (population growth boosted to strengthen military power). Population growth and harvest failures lead to large-scale famine in 1867–1868 (8% dies).	Strong population growth, emigration overseas. Share of farmers in the population starts to decrease. Rural landless population is double the land-owning population. Limited imports and crop failure in 1918 lead to food shortages and Civil War.	Steady population growth, expansion of city network.	Steady population growth. Fast urbanisation and rural depopulation.	Slow population growth. Growing immigration, foreign seasonal labour on farms.
International trade	Grain imports from Sweden and Baltic countries. Exports of butter from Western Finland.	Butter exports doubles (north, east). Free trade of grains in 1780–1809. Growing imports of grains during the 1800s (not enough manure for the new fields).	Free trade of grains since 1864. Exports of dairy products increases (also timber). Agricultural trade balance turns negative in the 1910s: dairy exports halts and imports of grains, pork and eggs increases. Import becomes difficult due to the First Word War.	Grain imports from the US removes the food shortage in 1919. Exports of dairy products (profitable until the 1930s) and eggs. Imports of fertilisers, feed and fuels increase. In the wartime, imports of grains.	Overproduction of agricultural products all over Europe. Imports of bread grains, subsidised exports of animal products and feed grains.	Decreasing self-sufficiency in several products, start of net imports in meat. Steady deterioration of the agricultural and food trade balance: negative trade balance grows by sixfold in 1994–2018.
Agricultural policies	Favourable policies for colonising new areas since 1300s. Independent farmers. Domestic production.	The Great Partition enables independent farming decisions and moderate growth of productivity. Establishment of crofts allowed since 1743. Both policies promoted clearing of new land and population growth (the number of crofts grows by tenfold in 1760–1860 contributing to 1/3 of the population growth).	Change in the policy focus from self-sufficiency to comparative advantage (animal products > crop products). First agricultural subsidies introduced. Increasing value of wood and forests; crofter issue becomes political.	Crofters gain independence: lots of small farms are established. Introduction of protectionist agricultural policies to guarantee self-sufficiency (especially in grains). Establishment of public grain storage in 1928. Start of complicated and contradictory agricultural subsidy policy.	Agricultural policy as a social policy, focus on small family farms. Development of agricultural income was detached from supply and demand. Increasing complexity and inconsistencies: restrictions on and support for production at the same time. Strict import protection (quotas, licences, levies, duties).	Adoption of the Common Agricultural Policy: common market, common finance, community preference. Abandonment of the concept of national self-sufficiency. Additional nationally funded subsidies. Heavy bureaucracy and control. Institutionalisation of agri-environmental policies.

Appendix B. Systemic properties of the agrifood regimes in Finland

Phase of the cycle	Resources (potential)	Connectedness	Resilience	Feedback loops	Agency
Expansion regime 1334–1721. Basin of attraction: Extensive mixed farming based on permanent fields and meadows in the west, slash-and-burn agriculture in the east.					
Exploitation 1334–1549	Land resources available to settle and clear new land.	Interdependency between peasant and the crown increases along with the willingness of the crown to collect more taxes.	Agricultural hardships are common, but no widespread famines.	Population pressure and politics favouring colonisation promote the expansion of settlements and cultivated areas.	Expansion of farming towards uninhabited areas is a private and family enterprise, supported by the crown.
Conservation 1550–1694	Provision of more taxes for the crown and services to the nobility by the peasants degrades the resource base. Harsh climate period cuts yields (Little Ice Age). Population base and tax	Centralisation of state governance (creation of the basis for a modern Nordic state). Specialised production of bread grains. Peasant are tied to serve two ends: to produce more food and to	Hunting for fur animals lead to their local extinction. Desolation of farms due to inability to pay taxes.	Wars and increased taxes put a burden on the peasant farmers and halts expansion. Overexploitation of fur animals limits livelihoods in the peripheries.	Deprivation of the peasants by the crown and by the nobility in the 17th century.

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Phase of the cycle	Resources (potential)	Connectedness	Resilience	Feedback loops	Agency
	revenues start to decline from 1570s onwards.	serve better the crown and the nobility.			
Release 1695–1721	Resources are both lost (wars, famines) and released (from fiefdoms).	Reduction of the fiefdoms releases established institutional relationships; nobility loses power and property.	High dependency on bread grains results in hunger. 25%–30% of the population dies due to famine during the Great Death Years 1695–1696; The Great Northern War in 1700–1721 increases losses.	The nobility and the crown lose control, focus is on survival.	Resourceless peasants are burdened by continuous wars.
Progressive regime 1722–1868. Basin of attraction: Extensive mixed farming based on permanent fields and meadows in the west, slash-and-burn agriculture in the east.					
Reorganisation 1722–1749	Period of enlightenment and appreciation of knowledge and innovations, new crop varieties.	Abolishment of the land ownership privileges of the nobility.	Peaceful and climatically favourable period.	Establishment of crofts and the adoption of new ploughing technologies promote expansion.	Improved opportunities for the peasants due to the right to establish crofts and better access to knowledge.
Exploitation 1750–1809	Basic Land Consolidation increases productivity and innovativeness. Strong population (and labour) growth. Reduced tax burden due to reorganisation of the military system. University-level agricultural education begins. First Finnish agricultural extension materials (people are becoming literate).	Increasing trade and exports of agricultural products. Free trade in cereals. Incremental innovations in farming techniques. Advisory organisations are founded.	The period is depicted as peaceful, although Central and Eastern Finland suffers from food shortages on a regular basis. Grain exports from south-west Finland.	Within the slash-and-burn system: high production capacity and demand for workforce promote population growth and expansion. Within the field farming system: Basic Land Consolidation, incremental innovations, establishment of crofts and decreased tax burden promote expansion and population growth.	Rights of the peasants are strengthened further. Basic Land Consolidation from the 1750s onwards allows farmers to make individual decisions about farming practices.
Conservation 1810–1865	The limits of expansion are approaching in land use.	Establishment of central governance along with the adoption of Russian rule. Centralisation of land ownership. New local farmers' unions are founded, but their management takes place top-down. First steps of regional specialisation. Growth of foreign trade, which leads to centralisation of wealth.	Population is growing and spreading northwards. Crop yields are decreasing due to nutrient problems. Cheap grain from Russia starts to flow in due to removal of customs; dependency on grain in diets grows further. Food security is increasingly sensitised to climatic fluctuations at the northern edge of grain production zone.	Population growth asks for expansion of fields in the west, which leads to competition between meadows and fields. Availability of manure limits the productivity of fields in the west. In the east, population growth asks for expansion of slash-and-burn agriculture which leads to diminishing forest cover. In both areas, the result is decreasing room for further expansion of agriculture. Increasing population also leads to increasing hunting pressure in the woodlands and disappearance of moose and deer.	Rural inequality grows especially in the western parts of the country due to population pressure and centralising land ownership; the situation of landless population is getting more difficult. Centrally established agricultural organisations do not lead to extensive grass-root involvement of farmers.
Release 1866–1868	The limits of production growth are met with the technology in use.	Existing production systems start to disintegrate.	8% of the population dies during the Great Hunger Years 1867–1868.	The capacity of extensive and grain-oriented farming to feed the people is at stake.	Peasants have a pressure to adopt new practices.
Cattle regime 1869–1918. Basin of attraction: Grass cultivation for cattle feed on permanent fields; reliance on comparative advantage in international trade.					
Reorganisation + Exploitation 1869–1904	Introduction of iron tools such as ploughs. Timber trade provides additional income for the farmers and enables investments in new technology. Milk production grows due to increased availability of cattle fodder. Agricultural education is institutionalised. Synthetic fertilisers and fossil fuels are introduced. New crop varieties and cattle breeding. From 1860 to 1900, number of employed in primary	Importance of international trade grows due to removal of customs. Exports of dairy products and imports of grain, pork and eggs.	Commercialisation of agriculture implies a trade-off between the commercial production and own consumption on the farms. Growing reliance on markets to maintain resilience of the food system.	Rotational farming practices, new plough technology, new knowledge, industrial-scale production of iron, new income sources and new markets for dairy products promote increasing productivity and specialisation.	Strong sentiment towards animal-based production systems instead of reliance on grain production. Local agricultural organisations and cooperatives are formed bottom-up.

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Phase of the cycle	Resources (potential)	Connectedness	Resilience	Feedback loops	Agency
	production grows from 0.5 m to 0.7 m.				
Conservation 1905–1917	Economic recession, unrest, poor harvests (bad weather) and imports of cheap grains undermine farm development.	Centralisation in the governance of the cooperatives. Dependence on international trade. Agricultural policies strengthen and lead to increasing food prices.	Global political instability manifests the vulnerabilities arising from the reliance on international trade. Harvest losses. Low self-sufficiency in other than cattle products.	Agricultural policies aim at regulating farmers' incomes and food supply, which results in food price increases and increasing tension between farmer and worker populations.	A more centralised, collective agency takes place.
Release 1918	Conflict over resource (land) ownership contributes to the start of the Civil War in 1918.	Dependence on international trade becomes a problem due to ceased imports resulting from the First World War.	Grain imports from Russia cease and self-sufficiency is low, which lead to shortage of food and unrest culminating in the Civil War in 1918.	Increased specialisation in cattle products and low self-sufficiency in other products leads to food shortages when import channels flounder.	Escalating conflicts between the farmers/ landowners and workers/ landless people.
Premodern regime 1919–1944. Basin of attraction: self-sufficiency in food driven by fossil energy.					
Reorganisation + exploitation 1919–1929	Fossil fuels and synthetic fertilisers become common. Mechanisation proceeds rapidly, e.g. combustion engines. Redistribution of land resources along with independence of crofters.	Adoption of protectionist agricultural policies in products reduces external connections and intensifies internal connections within the national food system. Extensive imports of feed, fuel and fertilisers.	Growth and intensification of production results in a change from food scarcity to occasional surpluses.	Promotion of small-scale farming and establishment of many small, independent farms.	Reorientation towards self-sufficiency. Crofters gain their independence and small-scale farming develops.
Conservation 1930–1938	Introduction of the agricultural support system.	Strengthening of the protectionist policies deepens internal connections within the national food system further; regional specialisation intensifies.	Turbulent time is characterised by forced sales, hardships and again recovery.	Introduction of policies to regulate production. Increased dependency on external inputs.	Farmers' economic situation is fluctuating; occasional farm failures.
Release 1939–1944	Resource base narrows due to wartime economy (labour, horses, machines).	Wartime economy and central regulation replace many commercial connections.	Food shortages during the war years due to decreasing imports of foodstuff and inputs accompanied by difficult weather conditions.	Limited availability inputs and labour in the war years (men were at war) lead to a decrease in animal production. This results in the decline of fertilisation (manure), which brings about food shortages.	Focus on survival.
Modernisation regime 1945–1994. Basin of attraction: self-sufficiency in food driven by fossil energy.					
Reorganisation 1945–1955	Oil, combustion engine, synthetic fertilisers. Reconstruction mentality, new farms become established and new agricultural land is cleared.	Policies aiming at self-sufficiency in products, extensive imports of inputs.	Recovery from the wartime economy and encouraging policies.	Establishment of many small, independent farms. Subsistence of refugees, national self-sufficiency, food security and social integration go hand in hand.	Resettlement of war refugees. Post-war reconstruction and clearing of new agricultural land. Strong reconstruction mentality.
Exploitation 1956–1969	Increasing use of fossil fuels, fertilisers, machinery. Agricultural subsidies, education and extension, plant and animal breeding. Increasing field acreage.	Agricultural policies to safeguard a comparative level and development of farm income in relation to other groups (cohesive or social agricultural policy).	Increasing productivity and crop yields. Self-sufficiency improves in products but deteriorates in inputs.	Clearing of new fields and intensification of production lead to increase of production and gradually to overproduction. Increasing input of fertilisers leads to increasing yields, which results in more money to be invested in more nutrient inputs and machinery.	Key role of farmers, input suppliers and advisory organisations in the adoption of new knowledge about input-intensive and machinery-based farming techniques. Farmers are 'safe' and indemnified by the state.
Conservation 1970–1989	The subsidy system becomes more extensive. Limitations in the possibilities to expand production. Decreasing field acreage.	Increasing specialisation both horizontally (production lines) and vertically (growing dependency on input suppliers and food processors). Institutionalisation of the extensive subsidy system.	Environmental problems accentuate especially in nutrient management. Farm development is halted.	Agricultural production is at the same time encouraged and restricted. Increasing application of fertilisers reduces the need for fallowing or using manure. This leads to weed problems which is alleviated by increased application of herbicides. The herbicides allow monocultures which promotes divergence between animal husbandry and crop cultivation. This results in the accentuation of environmental problems.	Very limited possibilities for farm growth, investments in productivity rather than in structural development.

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Phase of the cycle	Resources (potential)	Connectedness	Resilience	Feedback loops	Agency
Release 1990–1994	Policies limiting farm development are gradually relaxed in the anticipation of EU membership.	Old agricultural policies become gradually dismantled in anticipation of accession to the EU.	Part of the population suffers from hunger during the economic recession, demand for emergency food supply ('food help') increases.	Dead end: impossibility to expand production without effective market demand becomes obvious, increasing farm subsidies prove difficult, negative impacts of continuous intensification become visible, halted structural development of farms highlights low international competitiveness.	Farmers oppose EU membership.
Globalisation regime 1995–. Basin of attraction: maintenance of European production in global markets by means of subsidies.					
Reorganisation + exploitation 1995–1999	While producer prices are cut by 40%, a very extensive subsidy system becomes a new source of potential for agriculture.	Agri-environmental management institutionalises. Increasing centralisation in production, input supply, processing and retail trade. Introduction of extensive regulation and control of farming activities.	'Food help' institutionalises. Rise of organic farming and diversification of farm activities.	All obstacles for farm expansion and all specific subsidies for small farms are removed; average farm size increase by 1 ha/year (before EU accession 0.1 ha/year). Strong price cuts and constantly increasing input prices motivate farmers to increase the number of hectares as the subsidies are paid per hectare.	The number of small farms (1–20 ha) decreases by 36% in 1995–2000. The remaining farms start investing to grow or diversify supported by subsidies and released resources.
Conservation 2000–	Potential and resources are concentrated in the hands of a few (input suppliers, farmers, processors, retailers).	Heavy bureaucracy, high level of global interconnectedness, oligopoly in trade.	Climate change is established as a phenomenon and force field. Specialisation strategy replaces diversification strategy on developing farms. Reorientation at the farm level becomes difficult.	Incentives for owning the means of production grow further in relation to incentives to produce, which fortifies the centralisation of resources.	Power basin in the food chain lays increasingly in retail and input suppliers. Farmers' room to manoeuvre becomes limited between rising input prices, stagnating producer prices and high dependency on the agricultural support system. Mental health of farmers deteriorates.

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