The complexity of the food transition: a social simulation perspective

Wander Jager[1]*

[1] University College Groningen, Groningen, The Netherlands

Abstract

This paper first discusses the complexity of a transition in the food system, taking the stance of a system-of-systems approach where cascading effects can happen. A complexity perspective is taken in explaining transitional dynamics and their limited predictability. Following that, we focus on the social and behavioural dimensions of transitions. Here we zoom in on human needs as fundamental drivers, explaining how tensions between different needs may lay at the root of individual and social tipping points. Agent based modelling is explained as a methodology to simulate these social and behavioural dynamics, offering a tool to address the human factor into modelling the food system-of-systems. It is discussed that such agent-based models should integrate different behavioural drivers and processes to be capable of modelling transitional dynamics.

Keywords

transitions; human needs; agent-based modelling; food; climate change

1. Introduction

As a species, we are increasingly becoming aware of our impact on the biosphere of Earth. However, there is less clarity regarding how, and in what direction to change our behaviour to improve our co-existence with other life in the biosphere.

A key reason for this lack of clarity is the complex nature of our species functioning within the wider biosphere. Traditionally, scientific disciplines have been focussing at parts of the system, study it in detail, and possibly propose solutions from this lens. Bringing these different disciplinary insights together in a multidisciplinary perspective has proven to progress our knowledge of sub-systems and possible interventions. However, these disciplinary lenses combined do not provide a clear view on processes transgressing disciplinary boundaries. As a consequence, our understanding of how transitional dynamics cascade through various systems is still rather limited.

Sometimes we are amazed when we discover such cascading effects. For example, Piersma (see Kentie et al., 2013) explained how the emergence of a Chinese middleclass combined with a scandal of polluted baby-milk resulted in an increase in demand for high quality Dutch milk. The quota on the production of Dutch dairy, to protect the market prices, was released, resulting in an upscaling of production and intensification of mowing. This caused significant nest failure in the migrating godwit, causing many godwits to early return to the African west coast. As a consequence, the African farmers were confronted with godwits foraging on the new planted rice, forcing them to reallocate the early rice planting to more forested areas.

Correspondence:
Contact W. Jager at w.jager@rug.nl

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This story exemplifies how systems-of-systems work, and why a transdisciplinary perspective helps bringing different disciplinary lenses together in creating an overview of the causal loops and cascading effects in networks of systems. Modelling system-of-systems (Little et al., 2023) is a key approach in systematically exploring transitions and cascading effects that spill over from one system to another.

The food system is a typical example of a domain where many subsystems are connected through many feedback-loops, such as production, consumption, international trade and so forth. Especially human behaviour, as consumers but also in other different roles, plays a key part in transitional dynamics. This paper will focus on a social complexity perspective on transitional dynamics, and sketch a perspective on how agent-based modelling can contribute to bringing relevant behavioural drivers and processes into a system-of-systems approach. This may contribute to improving the behavioural perspective in models addressing transitional dynamics in system-of-systems.

2. Food as a complex system-of-systems with cascading effects

This paper takes food production and consumption as an example of a complex domain that covers many systems in our society, and has a high impact on global biodiversity. Food relates to the needs and emotions of people at the micro-level, relates to many processes in society at a meso level (local emissions, land-use) and addresses the global macro level (biodiversity, climate). Lowering meat and dairy in our diets seems to contribute to reducing our negative impact on the biosphere (e.g., Scarborough et al., 2014; Poore & Nemecek, 2018), however, a transition to a much more plant-based diet may require an orchestrated approach addressing multiple subsystems simultaneously.

Food production and consumption covers a large number of connected systems that can be studied using different lenses relating to the micro, meso and macro levels. The scale of these levels is sort of arbitrary, as from an individual perspective the food metabolism of our cells can be considered as a micro level system, our organs as different meso level structures, and our full body as a macro system. This paper chooses to consider individual humans as the micro systems, the different organisations people engage in as meso systems, and processes that span the globe as macro level. Key is that a system-of-systems approach is proposed, and that the different levels correspond to scientific disciplinary lenses addressing particular system levels. Hence besides being cross-scale, the system-of-systems approach is also connecting different disciplines, and can be considered to be a transdisciplinary approach.

A far from complete and Dutch oriented narrative may illustrate some of the complex dependencies in the food system-of-systems. We start with the diet of people (micro-level). Especially in rich countries, meat and dairy products are valued by many (culture). It is only in recent times that the abundant consumption of meat has become affordable for many people, and the meat-rich diet of nobility trickled-down through society affecting the food habits of many. For many, a good piece of meat is the centerpoint of a decent meal. Milk is an ingredient used for many products, ranging from large varieties of yoghurts and desserts, to very expensive cheeses. At the meso-level, the farming system co-evolved with this increased demand. This was amplified by the Dutch national policy after the second world war, which focussed on preventing a famine as had happened in 1944. As a consequence, agricultural policy has been focusing on increasing productivity by industrialisation (efficiency, upscaling). The upscaling of meat and dairy production has developed in an industrial production process that now involves importing animal-food (soy), fertiliser and the large-scale use of preventive pharmaceuticals (anti-biotics). The production has risen so much that the Netherlands has become one of the main food exporting countries, and this agricultural production is a significant component of the national economy (meso level). The investment in upscaling agricultural production is supported by banks trying to make higher return-on-investments. Some of these banks have their roots in cooperations of farmers, e.g., Raiffeisen bank and Boerenleenbank (translates a farmer's loan bank) merged into Rabo, which is currently a large investor in agribusiness. The animal feed and fertiliser industries have also grown into major businesses, and the very rich companies not only invest a lot in lobbying, but seem to provide a financial basis for a new and very popular political party (meso level) representing farmers (BBB – Boer Burger Beweging: Farmer Civilian Movement, currently being one of the largest parties in the polls (November 2023). The import of soy beans, in particular, for livestock feed is a transcontinental economical process (macro level), which implies trade agreements between different countries and international trade agreements (e.g., NAFTA). The increased demand for soy is met by transforming rainforest areas in the Amazon (Brazil) into agricultural land (meso level). National and regional policies regarding to this transfer affect to what extent this is being supported. Individual people (micro-level) may vote for a president that is promising economic growth and a higher income. Indigenous people may be forcefully removed from their land, and end up being marginalised (micro level).

Currently it can be observed there is a rising interest in a plant-based diet, and especially highly educated people (status) seem to increasing be shifting to a vegetarian or vegan diet (micro level). Especially bio-spherical values, health and animal-wellbeing are leading motives (e.g., Rosenfeld, 2018). These motives are often contested by people being very attached to their meat-eating lifestyle, and also many livestock-farmers are resistant to the narrative that society needs to change (values – micro level). In the Netherlands, the discussion is currently narrowing down on nitrogen emissions (NH_3), which should be reduced drastically according to the government (meso-level). This is accompanied by plans to buy out farmers and transfer the land-use. Here also the system of housing comes into the equation, as the Netherlands needs more space to host an increasing population (housing crisis). The discussion on the transition to a plant-based society thus elicits emotional discussions on the ending of long (family) traditions of producing meat and dairy products, the improper use of the nitrogen emissions to forcefully create more area for housing, and the sensitive discussion on immigration in the Netherlands. Obviously, this leads to strong polarisations in society, and possible political instability (meso level). Farmer protests in The Netherlands have led to the blocking of highways and disturbing the economy in 2022.

A key question is how a transition towards a plant-based society can be realised by supporting changes in the different subsystems of the food system. It seems that a national decrease in demand for meat and dairy products may have impact on the meat and dairy farmers, but considering the large export market, this effect may be limited. The banks could change their funding schemes, and support farmers to make a switch to arable farming and growing different crops (if possible). However, it has to be realised that such a change will disrupt an old culture, and that norms and values of farmers (identity) play an important role, next to financial-economic reasons to change. The presence of social support by other farmers seems to be an additional dimension affecting farmers motivations and incentives to change their practices (micro level). As an example, the dairy farmers on the Dutch island of Schiermonnikoog were convinced by biologists that their nitrogen emissions were harming the adjacent natural reserve, and as a collective they decided to reduce their livestock considerably, and started to create more added value from their milk by producing locally branded cheese (Erisman & van Wijk, 2022). Changing the prices of livestock feed (soy) and policies to stop or reverse the use of rainforest areas will also have an impact on the production-costs of dairy and meat. Also, farmers can decide to reduce their milk production by switching to different cow breeds[1] that do not require the high-protein and expensive fertiliser demanding grass types.

Policiesin such a complex system-of-systems can address different systems at different levels simultaneously. For example, people can be motivated to switch to a plant-based diet using persuasive messages addressing health, environment and animal-welfare. The agricultural system can be influenced by subsidies, taxations, regulations concerning land-use and emissions (e.g., nitrogen). The global level can be addressed through international trade agreements and bans, and taxations. It is obvious that changes happening in one subsystem will cascade through different systems, and hence policies addressing one system level will propagate through the system as a whole. A classic example of such a trophic cascade has been described in the case of the reintroduction of a few wolves in the Yellowstone National Park, which drove the elk away from the flatter areas, allowing for trees to grow, creating conditions for birds and insects and beavers to flourish, and as a consequence the whole ecosystem and landscape transformed due to the introduction of a few wolves (see Fortin et al., 2005). Returning to the food system, the complexity arising from the many feedback loops in the full food system makes it difficult to understand what dynamical processes may grow out of different (combinations of) events and policies. Whereas it is imaginable what sort of effects a single intervention on a specific scale in a specific system may produce, in reality policies - sometimes contradicting - will address systems at different levels simultaneously.

[1] The Frisian-Holstein cow breed is typically being used in high production contexts.

3. A perspective on transitional dynamics and cascades

Exploring possible pathways of a transition towards a plant-based society is an example of a systems-of-systems challenge. First of all, due to the complexity of the world, the impact of a plant-based transition may be difficult to imagine. Possible impacts of a plant-based transition can have surprising effects on e.g., the credibility of banks and the financial sector, perhaps even causing economic recession. The general health of the population could increase, and more plant-based food may as a consequence even result in population growth and a larger proportion of elderly people, which brings about new societal challenges, e.g., in housing, health-care and labour markets. Focussing on the agricultural sector, different scenarios may be imaginable of how this sector may respond with adaptation and innovation in a changing market. This all implies that while we are quite aware of the current position of society, there is a lot of uncertainty concerning the landscape of possible futures. The following Figure 1 is meant as a graphical metaphor in thinking about transitions towards different future states of society.

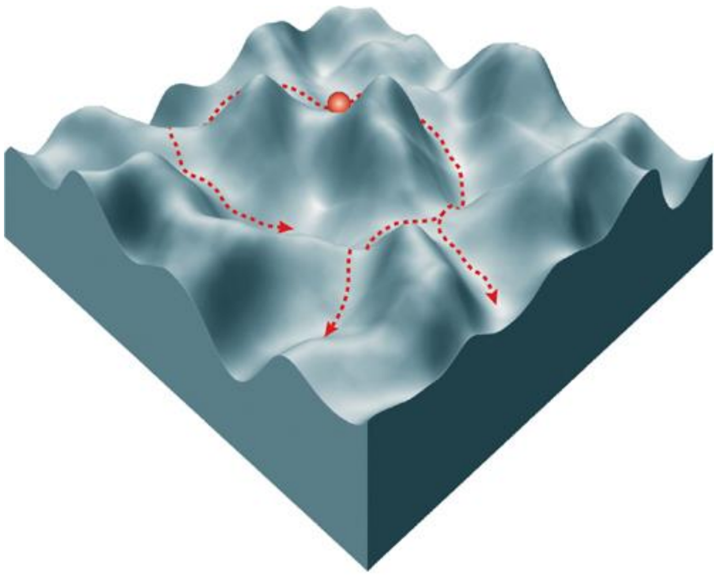

Figure 1: Attractor landscape. Source: MacArthur et al., 2009.

Figure 1 shows a 3D landscape, which originally was used to illustrate the epigenetic developmental pathways in a field of attractors. Here we use the same figure to visualise different states and trajectories of change in the food system. Attractors can be seen as the valleys in this landscape, and the state of the system as the red ball. The ball may move a bit, but has a tendency to stay within a valley, which can be described as being in a dynamic equilibrium, or homeostasis. Only when the dynamics become very turbulent, the ball may reach a pass, and tip over to another valley. This tipping of the ball towards another valley resembles the system transitioning to an alternative dynamic equilibrium. For example, a dairy farmer may experience good and bad years, but a transition would mean that the farmer switches towards growing vegetables. In the same way, a family may drastically reduce its consumption of animal originated proteins. And a CEO of a bank, perhaps convinced by his daughter, may start to strategically invest in sustainable agriculture. All these changes together can create a new dynamic equilibrium, where the new behaviours start reinforcing each other through a web of interdependencies.

As the figure illustrates, there may be different pathways for such transitions, and different valleys indicate the existence of several dynamic equilibria in the system. The occurrence of dynamical equilibria and tipping points was discovered in studying the sometimes-abrupt transitions in ecological systems. More recently, awareness has risen that in many complex systems such transitional dynamics happen (Scheffer, 2009; Kurahashi et al., 2023).

Using this figure as a metaphor, we can imagine that the current system-of-systems is in a dynamic equilibrium or homeostasis (a valley of attraction), and that many forces, acting as a network of interdependencies, keep this in place. Trade agreements, consumer habits, culture and farming practices all are forces that pull the system back to its current valley of attraction. There are also forces pulling and pushing the system to other valleys. These may relate to the crossing of natural boundaries, changing perceptions on animal-welfare, environmental responsibility and health, technological developments and economic developments. These push and pull forces can be aligned, but can also operate in different and sometimes even opposite directions. From a transitional perspective it is important to be aware of the different forces in the system, the existence of multiple dynamic equilibrium valleys, and different pathways towards these. Being aware of the simple metaphor of the figure, we realise that complex system of systems will address many more dimensions than the 3 (or 4 if you include time) as depicted in the figure. However, the essential ideas are that multiple dynamic equilibria exist in these systems, and that transitions between them are turbulent.

In the food system-of-systems, different valleys of attraction, or possible futures, can be imagined. Some strive towards a future of small-scale farming, based on biological and permaculture principles, requiring a cultural change in consumption, focussing on seasonal and locally grown food. Others focus on hi-tech plant grow systems, harvesting a lot of high-quality food from relatively small land parcels. Simultaneously, new technology is being developed to produce lab-grown meat, and meat-like substitutes allowing for the continuation of existing food habits without using animal sources. However, many uncertainties circumvent such developments regarding environmental impact and health effects and nutritional value of highly processed foods.

Reflecting further on Figure 1, we can expect that multiple valleys of attraction exist, and that parts of the system-of-systems may exist simultaneously in different areas of the landscape. For example, small-scale biological agriculture can exist next to hi-tech agriculture, and perhaps hi-tech agriculture even creates the conditions for small-scale farming to survive, as it may produce the necessary volume of food to feed the population, creating an up-market niche for high quality delicacies from small farms. Hence, where Figure 1 depicts a simple 3D landscape, we must be aware that a system-of-systems is composed of many more dimensions, and that different scientific lenses are needed in identifying its most relevant dimensions. Moreover, the landscape is not static but highly dynamic. A valley may become more attractive the more people gravitate towards it. In terms of the figure, some valleys may become deeper, and for example when more people change towards a plant-based diet, production systems may align with that development, thus creating a feedback loop (coupled dynamics) amplifying a transitional process.

Systematic experimentation with such system-of-system dynamics in the real world is not a realistic option. Here, simulation models offer a tool for exploring “transitional landscapes” in system-of-systems, and help identifying possible pathways for transitions. How much volatility in which subsystems is needed to get a system moving towards a different, higher quality dynamic equilibrium (valley)? Do synchronicities (coupled dynamics) in systems-of-systems support reaching tipping points? What sequencing of different policies addressing different subsystems produce more smooth (less turbulent) transitions?

Having a better knowledge of the cross-scale dynamics in a system may help identifying multiple transitional pathways to different future system states. Moreover, simulation models may explain what factors and processes are critical in determining the attractiveness of different pathways. This may open up a more integrated perspective on the policy options including a perspective on cascading effects in systems-of-systems. Coupling different models addressing different system levels seems to be a promising, but challenging way forward in better understanding such dynamics.

Understanding transitional dynamics does not automatically mean that we are capable of precisely predicting future states. Complex social systems, dealing with life itself, are always balancing between rigidity and turbulence, and hence are neither static nor chaotic (Heylighen, 2009). This dynamical balance, also coined “the edge of chaos” (Waldrop, 1992) is proposed to be the natural state living systems evolve to in order to be capable to adapt to changing circumstances and to self-organise. It can be imagined that transitional dynamics and tipping points in complex social systems, such as revolutions, disruptive innovations, hypes and fashions are also quite unpredictable, as when such transitional path are developing, the system swings to a more turbulent state, where small cause can have large effects. However, this does not mean that behaviour in social systems is not predictable at all. On the contrary, social complex systems often lean towards the more static side of the balance, where habits and norms serve as stabilising forces. Self-organising forces can give rise to quite stable patterns and sometimes even lock-ins (Heylighen, 1997). When a social system is in such a more static position in a valley, it is usually possible to predict how an intervention results in a temporal and limited change in behaviour. Especially within the field of marketing, elaborate statistical models are being used to predict, for example, changes in market shares as a result of pricing and advertising strategies. However, when the dynamics in a social system become more turbulent, the system may be capable of tipping over to a new state, and precisely these dynamics are confronting us with uncertainty and the possibility of multiple outcomes. A better understanding of these dynamics does contribute to identifying, or even stimulating conditions for a transition to happen. Here, simulation models may contribute to our understanding – not predicting - of transitions and help in the identification of possible pathways and alternative future system states.

A key challenge here is to represent the key drivers and processes guiding the behaviour of humans in a convincing manner. Considering that we deal with large populations of heterogeneous and interacting people, agent-based modelling offers a computational tool to simulate the social complex dynamics that play a key role in transitions involving behavioural change. Simulating such dynamics in the context of a food transition that drastically reduces the use of animal originating proteins requires that we first capture the key drivers and processes of human behaviour regarding the consumption and production of different types of food.

4. Human behaviour in food transitions: a needs perspective on individual and social tipping points

One of the key challenges in modelling the food systems-of-systems is capturing the behaviour of the human population, currently consisting of eight billion people. In the context of food all these people play their roles, in the first place as consumers. People choose what they eat, considering the options that are available to them. Sometimes people experience an individual tipping point, e.g., when they decide to become vegetarian or vegan. For example, people may have been supressing guilt for eating meat for environmental and animal-welfare reasons, and one leaked video on animal abuse may be sufficient for a person to tip over to a plant-based diet and become verbal about this change. Next, many people play a role in the food production and processing chain. Here people are active in farming, retail, restaurants, dairy industry, slaughterhouses, transport, livestock food production, fertiliser production and so forth. Many people have vested interests in the existing "valley of food production and consumption", which makes them reluctant to change. However, the more individual people tip over to a more plant-based diet, the more attractive (socially accepted and widely available) this "plant-based valley" gets, and the chances increase that more people tip over, potentially causing a self-amplifying cascading effect. Hence, tipping points can be identified at the individual level and at the social level. These tipping points may also have a spatial component, as it seems that in cities the proportion of plant-based options in restaurants and supermarkets is currently higher that in rural areas.

The pivotal element in a food transition is the large scale changing of diet by people. Dietary preferences and change confront people with sometimes difficult trade-offs. For example, a meat eater confronted with the suffering of animals may experience unpleasant emotions, just as a vegan may suffer from being bullied by meat eating family members. In order to systematically analyse such trade-offs, and identify why and how people respond to such conflicts, a perspective on human needs is critical. Understanding the multiple needs of humans contributes to our understanding of what drives people's behaviour, and what barriers for behavioural change exist.

Needs drive the motivation of all living creatures to act in order to maintain or improve the well-being of the organism. Whereas for plants the needs seem to be relatively simple, more developed species have different needs, and humans are a species where needs have evolved into a complicated set of drivers that sometimes conflict with one another. It comes as no surprise that our needs (or desires, wants and utilities) and how to deal with inner conflicts have been a topic of scrutiny for several millennia. For example, in Buddhism the annihilation of our many desires may result in Nirvana (as a valued state). Both Plato and Aristotle refer to the divided nature of the human soul, having a human-rational part and desires and passions we share with animals. More recently, in the social sciences, several scholars have addressed the nature of needs, the pyramid of needs as proposed by Maslow (1954) as the most well-known approach. Other approaches that categorise needs and develop taxonomies are proposed by e.g., Kenrick et al. (2010), Max-Neef (1992) and McDougall (1928). Nussbaum and Sen (2004) address capabilities instead of needs, and self-regulation theory addresses more short-term impulses as drivers of behaviour (e.g., Baumeister & Vohs, 2007).

The taxonomy of human needs developed by Max-Neef (1992) has been used in practical settings within the context of developmental economics. The nine needs Max-Neef distinguishes are subsistence, protection, affection, understanding, participation, leisure, creation, identity and freedom. Needs can be fulfilled by satisfiers, which are defined as "...everything which, by virtue of representative forms of being, having, doing and interacting, contributes to the actualisation of human needs". Whereas the first seven needs have existed since the origins of homo habilis, and, undoubtedly, since the appearance of homo sapiens, the latter two are assumed to have been developed later in the evolutionary process. Furthermore, Max-Neef (1992) hypothesizes that needs nowadays felt by some people, e.g., the need for Transcendence, may somewhere in the future evolve into a universal need.

Food is connected with several needs. Obviously, the basic need for nutrition is a key driver of behaviour. This basic need has a short time dimensionality, as people need to eat regularly. People, just like all other animals, have a taste preference for certain types of food, and we especially seem to be hardwired to like fatty and sweet nutrients (e.g., Drewnowski & Greenwood, 1983). With respect to meat Mullee et al. (2017) report "good taste" to be the most mentioned motivation to eat meat, both in omnivores (23.9%) as in flexitarians (23.1%). However, on a more cognitive level people can also reflect on how healthy their diet is. Currently health is one of the important drivers of reducing meat consumption (e.g., Gjerris, 2015). Especially the consumption of red meat and processed meat is connected to higher risks of illness, in particular coronary heart disease, type 2 diabetes and cancer a meta study reveals (McEvoy et al. , 2012). On the contrary, the prevalence of vitamin B12 in meat is often mentioned as a critical aspect of why we need meat in our diet. Especially vegans often suffer from health problems related to low vitamin B12 levels (Antinoro, 2012).

Social needs related to food are also a key driver of our dietary habits and preferences. We are raised by our parents and formed by our culture to appreciate certain types of food (preparations, acquired taste), and with cultural and religious taboos on eating some other foods. Meat consumption is often related to social bonding (Leroy & Praet, 2015), and is often regarded as a symbol of affluence and success (Font-i-Furnols & Guerrero, 2014). Meat is the food with the most meanings because of its association with higher status and the killing of animals (Fiddes, 1991; Rozin, 2004; Twigg, 1979). Meat is a food where several taboos play a role, as for example in the Jewish and Islamic tradition the consumption of pork is prohibited, in Hinduism the consumption of beef is taboo, and in western societies the consumption of dogs and to a lesser extend horses is taboo. Whereas in some culture the consumption of insects is appreciated, in for example western culture most people are very reluctant to try e.g., fried grasshoppers or mealworms.

It is important to realise that the social bonding associated with the consumption of meat is not an exclusive human characteristic. For example, in chimpanzees, sharing meat by alpha males is supposed to function as a social tool to develop and maintain alliances with other males (Mitani & Watts, 2001; Hockings et al., 2007). Also, in humans, meat has a metaphorical relation with maleness, and especially eating meat from mammals is associated with maleness (Rozin et al., 2012). The reader may think about the typical alpha male distributing burgers at a BBQ.

Not only personal taste, health considerations, and social norms are important for people's food preferences. Also values regarding environmental outcomes and animal wellbeing are important to many people. Increasingly, people are becoming aware of the environmental implications of a diet including meat and dairy (e.g., Scarborough et al., 2014; Poore & Nemecek, 2018). Also, people become aware of the problematic wellbeing of animals in the (industrial) meat and dairy production. Hence an important value to reduce or stop eating meat or products originating from animals is a person's personal ethics concerning how to treat animals (e.g., Gjerris, 2015).

The perspective on needs makes clear that people are often confronted with internal conflicts in their consumptive behaviour. When a person likes to eat meat and dairy, and is confronted with information regarding health, environment and animal wellbeing, an internal conflict arises which is called a cognitive dissonance (Festinger, 1957; Harmon-Jones & Harmon-Jones, 2002). The same dissonance between personal need and social needs can happen when a vegetarian or vegan is encountering a social environment that is very "meat oriented".

The dissonance experienced in such situations arouses stressful feelings, and people generally try to find strategies to alleviate this stress. Piazza et al. (2015) found that individuals can respond to this dissonance in two ways: one can reject meat consumption, bringing one's behaviours into alignment with one's moral ideals, or one can bring one's beliefs and attitudes in line with one's behaviour through various psychological strategies. Joy (2010) for example describes the employment of denial, justification and cognitive distortions to alleviate guilt about eating animal products. Also, Loughnan et al. (2010) report that meat eaters often withdraw moral concern from animals and deny their capacity to suffer. The confirmation bias (Wason, 1960) further suggest that people are more likely to accept information that is consonant with their behaviour.

Considering that people prefer a consistency between attitudes and behaviour, people generally try to reduce the dissonance to remain in an existing behavioural (habitual) pattern, which can be seen as a valley of attraction or homeostasis. However, when the internal conflict is too much, people may tip over to a different dietary pattern. Sometimes this change may be gradual, e.g., many people become flexitarian. However, people may also be converted to a strictly vegan lifestyle. Such a transition may also imply that earlier attitudes and opinions that had been formed to defend against a dissonance (e.g., neglecting environmental and animal welfare issues) can also radically change to support the new diet choice. The classical example here is the smoker referring to a heavy smoking granddad that lived up to 90 years old, after quitting becoming a fanatic advocate for strict rules against smoking. The same can sometimes be seen in people becoming activist vegans.

When a dissonance exists between personal taste and habits in favour of animal products, versus values that promote a more plant-based diet, the opinions and behaviours of friends and family may serve as the force that can be decisive in transitioning to a different diet. Typically, in innovation diffusion processes it is the less socially susceptible people that first adopt a new behaviour (innovators), whereas the larger majority is more susceptible to the behaviour of peers (Rogers, 1995). This indicates that in a food transition the innovators and first adopters of a new diet are different people than the majority. Most likely, the people for whom the environmental and animal welfare values (transcendental needs) are highly important, are also the ones experiencing more cognitive dissonance related stress resulting from their meat consumption, and hence are the first to change towards a more plant-based diet. Here we also have to be aware that many people have other concerns than the environment and animal-wellbeing, and whereas the relation between income and environmental awareness is complicated, it can be observed that many richer people also have a higher environmental concern (Fairbrother, 2013). Environmental and animal welfare concerns thus may be only at focus when more basic needs are not under threat (see e.g., Ahonen, 2017). This may also explain why citizens of higher income countries contribute more to environmental protection than citizens in low-income countries (e.g., Lo, 2016).

Whereas a dissonance experienced by a consumer regarding the use of animal proteins can be resolved "relatively easy" by changing behaviour, we have to realise that such a transition may be much harder for people working in the meat and dairy production. Farmers that come from a long-lasting tradition in producing meat and dairy may especially experience very stressful dissonances when confronted with negative information on their behaviour, because changing behaviour as a farmer is a costly and risky enterprise, and may have serious impacts on their income and social standing among fellow farmers. Whereas some farmers succeed in making steps towards steering away from intensive animal production (Erisman & van Wijk, 2022), it comes as no surprise that other farmers forcefully protest against interference with their farming practices, and strongly reject claims regarding environmental impacts and animal suffering.

Stress resulting from dissonances has a serious impact on human behaviour. Typically, stress is related to losing control and/or predictability over a situation, absence of social support and a perception of things getting worse (Sapolsky, 1994), which seems to apply very much to the uncertainties associated with a societal transition. A typical response to such uncertain and stressful situations is to talk with friends and family, to observe what other people in comparable situations do and express, and to listen to the opinions of various opinion leaders (politicians, celebrities) through multiple channels. Especially when certainty is sought for, people tend to listen to authorities that express with confidence what will happen and what needs to be done. When these expressions target the needs that are in focus, it is likely that such an authority will be perceived as a leader with a vision to help resolve one's problems. This also explains the different social-economical background of the electorate for politicians focussing on long-term sustainability versus politicians that focus on issues like housing, food and energy prices. It also explains why people that have less concerns about their existential needs are often more liberal, whilst people that have concerns about their existential needs have a stronger tendency to become conservative (e.g., Jost et al., 2003). Hence concerns and stress associated with societal transition may trigger conservatism in people who are the most likely to directly suffer from changes such as taxation of meat and dairy products. People that have sufficient financial means and a high environmental awareness may very much express hope in a society that transforms to a more sustainable state. This uncertainty, stress and fear related to transitional dynamics thus may contribute to a polarisation in society between the more progressive liberal people and the more conservative people.

This perspective on needs and dissonances emphasises the behavioural complexity of a food transition, as individual behaviour changes and societal transitions are deeply intertwined. Processes at the individual level and societal level are amplifying each other. Whilst needs can be considered to be an essential driver of our food consumption behaviour, in much social scientific research the rich theoretical perspectives on needs are hardly being used in empirical studies. Much research in the social sciences addressing motives and values of people to change their behaviour is based on survey research. Especially nowadays it is relatively easy to obtain a large number of responses on a questionnaire that allows for statistical analysis of the different segments of people that display different motives and sensitivities for certain policies. However, there is a fundamental problem with using questionnaires. Not only do people have a tendency to answer in a biased manner to present themselves "better" than they really are, following a self-serving bias (e.g., Bradley, 1978), but important drivers of our behaviour are non-verbal in nature, and can be associated with brain and body systems that have limited communicative channels with our verbal cortical thinking. A classic example may be the verbal argumentation for driving a big car, which may be centred around the needs for comfort, safety and space to transport things, and perhaps even a mention about the aesthetics and joy of driving a certain car. However, motives related to demonstrating social power, dominance, or a display of sexual attractiveness are hardly mentioned, whilst we do seem to recognise such deep non-verbal motives. As discussed earlier in relation to diet, some important masculine and social power related drivers, as well as cultural identity motives may be associated with meat consumption. As mentioned earlier, one could think of the example of typical male behaviour in operating a barbeque and distributing the grilled meat.

Getting data on these drivers through questionnaires can almost be compared with interviewing a dog: while we are aware of a dog's needs, it is unlikely that you will get meaningful data. As a consequence, clear data on the need satisfaction of people are not available, and especially in modelling the dynamics associated with need satisfaction, a more interpretative approach ("verstehende psychology", Dilthey, 1922) seems to be an approach to include behavioural drivers that are less accessible through surveys. Hence, whereas the social sciences have been dominated by collecting empirical data through surveys, and conduct statistical analysis on these data, it seems that regarding important deeper drivers of behaviour there is a serious blind spot, requiring a different methodology to address. The paradigm of complex systems, and the associated methodology of agent-based modelling, allow for studying complex social dynamics. This computational modelling approach allows for formalising less cognitive drivers of human behaviour, and simulate how these may affect transitional dynamics in society.

5. Modelling social complexity using agent-based modelling

The social complexity perspective is focussed on the interactions between individuals (micro-level) and the group/community (macro level). This perspective embraces a dynamical perspective, emphasising processes of growth and changes in opinions and behaviours. Due to the feedback mechanisms in social complex systems, complex social dynamics such as exponential growth, tipping points and multiple pathways (scenarios) can grow from the many interactions in a multi-layered social system. In particular, the social complexity perspective addresses the processes of emergence, which explains how group phenomena grow from aggregated individual decisions, and downward-causation, where aggregate group behaviour determines what an individual person can and cannot do. A typical example of such an emergent phenomenon is a bank-run, where rumour can result in a self-fulfilling prophecy, and people also feel the urge to withdraw their money because so many other people are doing it. Such social dynamics play a role in making many behavioural practices "normal" and accepted, such as driving big trucks and SUVs, flying to holiday destinations, having a meat rich diet, but also a rising popularity of vegan diets and the increase in use of (e-)bikes in many cities. The social influences in such domains operate in a rich network of normative and informative influences, including family interactions (education), friends and colleagues, neighbourhood networks, social media, and public figures such as politicians and celebrities. When a strong "normality" is associated with a particular behaviour, it can be said to be "socially locked in", which relates to the valleys in Figure 1. Such social lock-ins can be interpreted as (sub)cultures. Because most people are engaging in particular behavioural practices, deviating from the normal practice is often seen as negative behaviour. Food systems seems to display such locked-in properties, and for example the cultural habits of e.g., the affluent barbeques in the West, the sacrificial feast involving large scale consumption of sheep in the Middle East and the slaughter of whales in Japan are considered to be normal, and critique is often not appreciated as it touches upon sensitive cultural values (identity). Transitions, especially when they elicit fear in people for losing something that is important to them, may cause a change that would be disruptive at both the system level and the individual level. This basically means that transitional pathways can be very difficult, and sometimes even violent as in the case of revolutions.

Getting a clearer perspective on possible transitional pathways may help in finding more smooth courses in trying to move away from a system state that is becoming harmful. Whereas many narratives and cases are available on complex transitional processes in real life, experimenting with such dynamics is problematic because of the large number of people involved, the longer time periods involved – sometimes a generation - and the lack of experimental control. Hence much knowledge on transitional processes remains on a more verbal narrative level. Here social simulation, where artificial populations are being created in agent-based computer models, offers an approach allowing for experimentation and exploration of what-if scenarios of transitional processes in behavioural systems (see e.g., Jager, 2021). In modelling social complex processes, replicating the processes of emergence and downward-causation requires the interaction between many different individuals. This social simulation uses the methodology of agent-based modelling, where many agents are programmed in a computer environment, and these agents can interact with each other following specified rules of interaction.

A classic example of a social application of agent-based modelling is the segregation model developed by Thomas Schelling in 1971. With this simple model, Schelling (1971) demonstrated how ethnic groups could completely segregate, whilst each individual would be happy in a mixed neighbourhood. In this model, the agents, represented by a black or white dot, would move to another vacant spot depending on the percentage of neighbouring agents with a different colour than themselves. Even if the agents were happy being in a 30% minority position, strong segregation still emerged. This influential paper demonstrated the intriguing capacity of agent-based models to dynamically connect the individual micro level with the macro societal level.

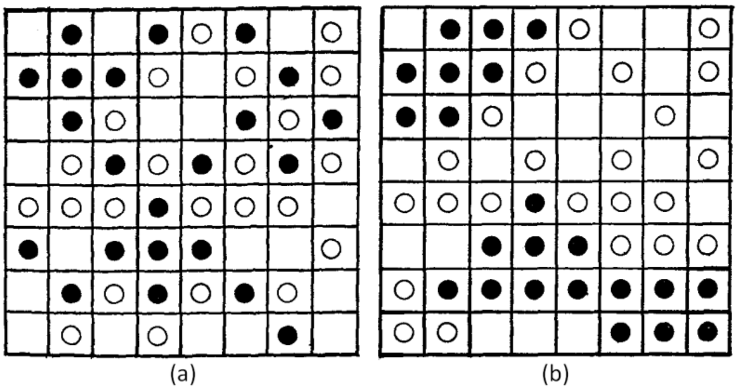

Figure 2: The initial condition (a) and a stable segregated pattern obtained after several iterations (b) (Schelling, 1974).[2]

The Schelling model was also considered by Schelling himself to be overly simple concerning the behavioural rules, and since then, the methodology of social simulation has evolved into a field addressing many social complex phenomena. Many publications using social simulations with rich behavioural assumptions address a variety of climate relevant issues, such as social-ecological systems, transportation behaviour, home energy use and consumer behaviour (for a review see e.g., Jager, 2021). Such social simulation models can replicate complex social dynamics in computer models, and multiple runs can reveal if different outcomes can emerge from relative equal starting situations, thus revealing fundamental uncertainties in such social systems. Also, policy experiments can be conducted for exploring possible futures of a case, testing how interventions may interact with social dynamics under certain scenarios. In this way, social simulation contributes to our understanding of how social dynamics play a role in transformative processes. In particular, social simulation models may identify

[2] To experiment with this model online visit:
http://www.netlogoweb.org/launch#http://www.netlogoweb.org/assets/modelslib/Sample%20Models/Social%20Science/Segregation.nlogo.

processes of tipping points, when a smaller group of pioneers or innovators succeeds in getting the attention and trust of a larger audience, causing an initial resistance against a change (conservative norm) that transforms into a join-the-bandwagon effect (see e.g., Nyborg et al., 2016). Running a model many times may identify situations where the success or failure of an innovation may depend on the behaviour of just a very few people adopting or not, which is very interesting from the point of supportive policy. Sometimes the persistence of one person in a community may make the difference in turning a community project into a success.

Whereas there is an abundancy of empirical studies addressing dietary choice, only a limited number of agent-based models has been targeting consumer behaviour regarding food and dietary choices. In particular not much simulation work has been done in addressing meat consumption and a change to plant-based diets. Thomopoulosa et al. (2021) developed an argumentative network model addressing arguments around vegetarian diets using an abstract argumentation approach. However, this is not really addressing dynamics and transitions in human consumption. The most advanced work in this domain is by Scalco et al. (2019), who address meat consumption in the UK, using the Theory of Reasoned Action (Ajzen & Fishbein, 1980) to address concerns about the impact of meat on the environment, health, and animal welfare, including social influences. The results are basically addressing the sensitivity of a population for price influences, and in terms of the dynamics, Scalco et al. (2019) address more the sensitivities within a dynamic equilibrium (valley) than transitional dynamics towards a different food system.

6. Agent-based models of human behaviour in system-of-systems

Simulation models of food consumption and choice are very relevant in a system-of-systems approach to understand the dynamics of transitions in complex systems. Due to their formal computational level, social simulation models open the possibility to connect social behavioural dynamics to other domain models, thus contributing to a systems-to-systems approach in modelling cascading transitions. For example, it becomes possible to explore the interaction between climate dynamics and behavioural dynamics. There is an increasing awareness concerning the relation between climate change, crop-fail, conflict and migration (e.g., Syria: Kelley et al., 2015). Projections of climate change and food production stress the importance of understanding such cascading transitional dynamics in socio-ecological systems, especially in times of climatic change (e.g., Knox et al., 2012).

With respect to a systems-of-systems modelling of the food system, interesting agent-based models have been developed addressing food supply chains, thus connecting different systems. Calisti et al. (2019) study how local producers can enter a market and change habits of consumers towards buying more local sustainable products. They address the food supply chain in their approach, and provide a good overview of existing agent-based models addressing such chains. This review shows that many models address farmers and markets, and some of these models address more actors, such as farmers, food processors, retailers and consumers (Gagliardi et al., 2014) or stockbreeders, retailers, consumers and stockholders (Buurma et al., 2017). Whereas such models address cascading effects in a basic system-of-systems approach, the behavioral models are (understandably) quite simple, not addressing individual and social transitions, nor the informational and normative processes taking place in a food transition.

In modelling individual and social transitions in complex food system-of-systems, it seems necessary to address networks of heterogeneous people having different interests and influences. A good representation of drivers and processes of human behaviour is needed to identify what transitional pathways are likely to happen, and where social tipping points have to be crossed in order to reach a different (more sustainable) food system. Social tipping points happen when individual behavioural changes accumulate towards a situation where increasingly the old norm is being challenged, and a new norm is emerging. Here we deal with emergent or self-amplifying effects, as the more people transition towards a plant-based diet, the more normal it gets, and the more people that are on the brink of a change will also tip-over towards a plant-based diet, thus further adding to the new norm. When a sufficient number of innovators or pioneers have made a change, local clusters with the new norm can emerge, contributing to the further spread through society of the new practice (Nyborg et al., 2016). Obviously, such changes cascade to other systems, as for example a voluminous increase of people switching to a plant-based diet will result in supermarkets adjusting their assortment, and food producers may change their production, funding schemes for agro-business will adjust, and new businesses may emerge.

In simulating the transitional dynamics in society, the foundations of human behaviour in simulated people needs to be represented. Whereas many theories of behaviour are available, and several of them are being used to develop agent-based models, a key problem is that social scientific theories address only parts of the drivers and processes of human behaviour that are relevant, and importantly, perspectives on conflicts between needs, dissonances and their role in individual and social transitions are not being addressed (e.g., Schlüter et al., 2017). Hence a key challenge in modelling systems-of-systems is to include models of human behaviour that represent the aforementioned behavioural drivers and processes in a sufficiently realistic manner. The implementation of social scientific and psychological theories in agent-based models is developing fast, and integrated models connecting different behavioural mechanisms is increasingly becoming available. Examples of architectures aimed at integrating cognition with social activity include the Consumat (Jager, 2000), FEARLUS (Polhill et al.. 2001; Gotts & Polhill 2009), dynamical affinity model (Bagnoli et al.. 2007; Carletti et. al. 2008), Agent_Zero (Epstein, 2014), Polias (Brousmiche et al.. 2016), BayesAct (Schröder, Hoey & Rogers, 2016), and co-development of beliefs and social networks (Edmonds, 2019). These integrated approaches are very relevant, as they aim to connect different processes in a causal framework that supports the modelling of drivers and processes that are causally connected. As such, these integrated models substantiate the demand for a dynamical social science (Nowak & Vallacher, 1998) or generative social science (Epstein, 2006).

As the perspective on (conflicting) needs and dissonance is particularly important in modelling the processes leading to individual and social transitions, this paper briefly introduces HUMAT as an integrated framework that is capable of simulating those processes, and that includes the aforementioned needs and processes of cognitive dissonance reduction.

7. HUMAT as an example of an integrated behavioural agent-based modelling framework

Within the context of the EU SMARTEES project, the HUMAT framework has been developed as a generic agent-based simulation platform that formalises and integrates different behavioural drivers and processes to support model development and data collection for model parameterisation (Antosz et al., 2019). The HUMAT socio-cognitive architecture (Antosz et al., 2019) constitutes artificial populations in which agents have dynamic beliefs about how satisfying behavioural alternatives are for their needs and values, and have social networks to communicate with one another about these beliefs. Different behavioural alternatives may evoke dissonances in the simulated people, and these can be resolved with different strategies. When, for example, agents are confronted with other agents engaging in behaviour that is conflicting with their values, the resulting social dissonance may cause agents to signal to the other agents' information to influence their behaviour. The other agents will be persuaded by this message if they perceive the sending agent to be reputable and part of their ingroup (similarity). In the context of a food transition, it seems that values related to environment and animal welfare play a role, but obviously also values related to the social meaning of meat consumption play a role. Using HUMAT as a framework for a simulation can explore under what conditions transitions take place, and in what situations polarisations may emerge between different food related lifestyles.

In the context of a transition towards a plant-based society, an integrated behavioural model as offered by the HUMAT framework represents social influence in the context of the (dis)satisfaction of different needs and values as motives for action, and hence seems to offer a simulation tool that can address the interlinkage between individual and social transitional dynamics. Using micro-simulation as an empirical basis, capturing properties of real populations regarding socio-economical characteristics, artificial populations can be built representing the spatial distribution of wealth, age, education, mobility behaviour et cetera. This representation helps in exploring how and where in a society individual transitions take place regarding consumption patterns as well as how transitions may develop at the societal level. As addressed earlier, the consumption of food and preferred diets are addressing many different needs simultaneously, and cognitive dissonances and emotions can play a profound role in dietary choices. The HUMAT framework as we briefly showed here offers possibilities for extensions with, e.g., emotional drivers such as hope and fear, and heuristics in informational processing such as availability heuristics or conformation bias. For an extensive description of the precise formalisations of the generic HUMAT framework we refer to Antosz et al. (2019).

This HUMAT platform has now been used to simulate a variety of empirical cases of social innovation, such as a referendum on closing a park for car traffic, joining heat network projects, establishing local city blocks banning transit traffic and islands transitioning towards sustainable energy (for examples see https://local-social-innovation.eu).

Within a systems-of-systems approach for the food system, a behavioural simulation can receive input from other models of systems, such as information on the environmental impacts, food production practices, and food prices and availability. As output, behavioural simulations can produce scenarios of dietary changes in populations, and associated opinion dynamics. These can serve as input for e.g., models of food production and markets, and policy models. For example, if a significant part of a population is resistant against financial policies aimed at stimulating a dietary change, this may translate in the rising popularity of political parties that also resist a change in agricultural practices.

8. Adding the behavioural system to a system-of-systems approach

In the field of social simulation, there is a stark increase in models that capture more realistically the dynamics of behaviour and the factors are of influence in the process of change. These are often used in addressing behavioural dynamics in different environmental relevant domains (e.g., see Jager 2021 for a review). Oftentimes such models are not interacting with models of adjacent systems such as food consumption, energy use and mobility.

Having more realistic social behavioural dynamics in system-of systems models opens possibilities for exploring how changes in food systems could cascade through society, resulting in changing of behavioural practices, which in turn may affect other systems, that may feedback into the behavioural system.

As an example, if the current development towards a plant-based food system gets traction in society, livestock will decline, and much land use will change. In an urbanising environment, such as the Netherlands, this raises questions if livestock farms are ending, how will the resulting land be allocated? Land-use models may project different crop types, but also rewilding and urbanisation of this land are options. Behavioural perspectives and responses to these options can be very different. In urban areas people may be valuing nature more, especially if accessible for recreation. For the rural population, sustenance may be more important and they may prefer economic (agricultural) activities over rewilding when land use changes. If these perspectives become strongly opposing, polarisation may slow down the adaptive capacity of society. However, frictions may also translate into a longer-term cultural change, which takes place over generations. For example, we could observe a development towards a culture where nature and culture are perceived as deeply intertwined rather than separate domains. This also translates into acknowledging the role of humans as active ecosystem engineers, rather than more protective nature conservationists.

Many other systems can be coupled to a behavioural module to explore possible cascading effects. Demographic models explore population dynamics and land-use related processes of urbanisation. Going to the system of our food consumption, a change towards more locally grown plant-based food can have impacts on the interaction between rural and urban environments. If the trend of smaller scale vegetable gardens continues, more labor is needed in rural areas. This may start a process of ruralisation, where urban areas that have been experiencing population decline, unemployment and aging populations now start growing and reviving again. This will have consequences in, for example, mobility and the social cohesion in villages (e.g., return of a school). The interaction between small-scale farmers and city-dwellers may be important in this process.

Healthcare is another example of a behaviour-connected system where large investments are being made forecasting future demand. Obesity is a current epidemic in Western society, caused by a diet abundant in fat and sugar (e.g., Catenacci et al., 2009). A food transition will impact this diet, and as a result some wide-scale problems such as obesity may diminish, but new ones may emerge, e.g., related to potential vitamin deficiencies. Importantly, forecasts of future health can feedback as an argument in changing diet. Hence expected behaviour informs healthcare, which in turn informs the people.

It has become clear that many systems can be coupled in a systems-of-systems approach, which confronts us with the scoping of such models. What (parts of) systems need to be included, and what parts can be excluded?

This question requires us to reflect on the intended use and the final user of the model. Whereas smaller models with a limited number of parameters can be analysed using an experimental design, the system-of systems approach confronts us with so many parameters that a classic experimental approach is difficult to follow. Machine learning techniques may be used in the future to discover e.g., cascading patters in a specified parameter range. The scientific value at this moment resides in the formalisation of interactions between different subsystems, which forms a computational and causal framework for interdisciplinary projects. Assumptions on e.g., behavioural change, now can be tested for the impact they may have on other systems, and how changes in these systems may feedback in the behavioural domain. Hence it can be expected that system-of systems modelling approaches will support the methodological basis for inter- or transdisciplinary studies of complex systems such as our food system. The more sub-models are developed that are designed to operate in a system-of-systems approach, the larger the library of sub-models becomes that can be recycled and adjusted for new projects and questions.

For practical policy making, system-of-system models are expected to contribute to an inter- or transdisciplinary perspective of policymakers dealing with complex – or wicked – problems. Having models demonstrating the potential cascading effects from certain policies will support more collaborative policy making, and reduce the risk of linear thinking in dealing with complex problems. Expertise from different disciplines will be used in an integrated setting, creating an awareness of the potential cascading effects and synergies in policy development. Also important is that not only short term, but also long-term dynamics can be included in simulations of system-of-systems, which may help policy developing long term strategic plans.

An interesting example of such an approach is the AASOC model that has been developed to capture the complexity of the COVID-19 pandemic (Dignum, 2021). This model also combines different systems in a large integrated systems-of-systems model, which has been used to support discussions on how to handle the COVID-19 pandemic. Strategies such as testing regimes, the use of digital tracking, school openings, policies on transportation and the like can be explored for the number of Covid-19 cases and socio-economic impacts. Such exercises can be done given different assumptions on the (change) virus characteristics, and population properties such as age and culture. This model has supported policy development in a number of countries, most notably Sweden. System-of-system models such as ASOCC do not provide simple predictions, but rather support discussions between experts from different backgrounds in understanding how developments in one system may propagate through other systems, and hence supports an interdisciplinary or transdisciplinary policy perspective on complex cascading dynamics in transitional processes in society.

9. Discussion and Conclusion

Climate change and ecological degradation lead to sometimes turbulent processes that cascade through all of society. Mitigation and adaptation to such changes requires a behavioural change of the population, but it is critical to be aware of the many systems that are both influencing this behaviour, as well as are responding to behavioural change. The food production systems as exemplified in this paper is an example of such a complex system-of-systems, but such a system-of-systems approach is relevant for understanding cascading effects in many more domains where a societal transition is happening. For example, in the energy domain we deal with geopolitical tensions translating in volatile prices of natural gas, the electrification of mobility leading to problems in grid-capacity, and different perspectives and expectations regarding the consumption and generation of power. Some futures are imagined with an abundance of electricity generated by fusion, others expect energy-poverty to increase in the near future.

Different interest and perspectives, driven by hopes for a better future and fears for (further) loss of quality-of-life may lead to a divergence in societies between people that have different visions on where society should go, and people that resist change from the status quo. This may lead to the loss of social cohesion and give rise to societal tensions, something that became clearly visible during the COVID-19 pandemic. Moreover, if action is required to address an emerging problem, such social tensions may reduce the adaptive capacity of a society to respond adequately to changing circumstances.

Modelling systems-of-systems is expected to contribute to a better understanding of possible cascading effects between systems, and the different points of attraction (dynamical equilibria) that can be identified as possible future states, perhaps existing simultaneously. For example, intensive industrial and sustainable vegetable production can exist next to small scale biological agriculture.

Having good simulation models of various systems and coupling them is expected to contribute to a better perspective on possible future states, and ways of navigating to desired futures without transitions being too disruptive to the lives of people. Recent developments in the modelling of human behaviour will contribute to a better perspective on the impact of transitions on the needs of people, and hence address impacts on quality-of-life. This may be important in helping communities to reflect on how to adapt to changing circumstances and developing plans for the future. Having a clearer perspective on how a future state of society may contribute to a better quality-of-life may be important to overcome a conservative response due to fear of losing quality-of-life. Finally, it seems critical to use co-creative processes in modelling different systems, and in particular the inclusion of the population in developing such system-of-systems models will require the involvement of citizens. Investing in deep conversations with, in particular, more vulnerable groups, and representing their needs and concerns convincingly in models, seems essential in making models a useful tool to support transitional processes. Reducing uncertainty and developing trust in the change will contribute to building support for changes if these are needed to adapt to a complex changing world.

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