nature sustainability

PERSPECTIVE

https://doi.org/10.1038/s41893-019-0419-7

A more dynamic understanding of human behaviour for the Anthropocene

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Human behaviour is of profound significance in shaping pathways towards sustainability. Yet, the approach to understanding human behaviour in many fields remains reliant on overly simplistic models. For a better understanding of the interface between human behaviour and sustainability, we take work in behavioural economics and cognitive psychology as a starting point, but argue for an expansion of this work by adopting a more dynamic and systemic understanding of human behaviour, that is, as part of complex adaptive systems. A complex adaptive systems approach allows us to capture behaviour as 'enculturated' and 'enearthed', co-evolving with socio-cultural and biophysical contexts. Connecting human behaviour and context through a complex adaptive systems lens is critical to inform environmental governance and management for sustainability, and ultimately to better understand the dynamics of the Anthropocene itself.

Human actions are a main driving force of global environmental change[1], giving rise to what some call a new geological epoch, the Anthropocene[2]. Major sustainability challenges, such as climate change and biodiversity loss characterize the situation. Ensuring a liveable planet and well-being for future generations will require changes in governance, technology, and not least individual human behaviour. Indeed, researchers and policy makers agree—progress towards sustainability will on an aggregate scale require a major behavioural shift[3,4]. Such behavioural change is both one of the biggest challenges to, and opportunities for sustainable development.

While acknowledging the critical role of human behaviour, we also need to recognize the 'new' reality in which this behaviour plays out. Humans have faced different challenges over the centuries. In human pre-history, the main focus was meeting basic biological needs, such as survival and securing reproductive opportunities. Even though altruism and capacity for collective action were important in these small-scale human societies, as societies increased in size and complexity, humans had to achieve large-scale coordination and conflict resolution. The dominant current socio–economic system and associated institutions emerged, at least in part, as a result of this challenge[5]. The dominant view of human behaviour in this system is often understood as individual responses to extrinsic material incentives only. However, we argue that the profound significance of human behaviour in shaping future pathways towards sustainability in the Anthropocene requires a richer understanding of human behaviour, taking into account the role of broader contexts in shaping behaviour and how it continuously co-evolves with changing local to global contexts.

As an interdisciplinary team of authors rooted in complex adaptive systems (CAS)[6,7] thinking and sustainability science, we propose to adopt a CAS lens on human behaviour, that is, to regard human behaviour as constantly evolving, as shaped by and shaping the CAS in which it is embedded[8]. Our CAS lens assumes: (1) diversity and individuality of system components (for example, humans, plants and animals); (2) that local interactions among these components create emergent patterns, which in turn shape interactions; and (3) constant change and co-evolution resulting from feedbacks or processes such as learning that favour certain types of behaviour or dynamics, thus affecting system functioning and outcomes[7,8]. Such an approach allows us to link and capture the interplay between the behaviours of diverse individuals, interacting within their broader socio–cultural contexts and the biosphere they are ultimately embedded within[9]. Understanding human behaviour in the context of CAS is not only of critical importance to inform environmental governance and management for sustainability, but ultimately to better understand the dynamics of the Anthropocene itself. It provides a means to understand potential pathways along which social–ecological relationships might evolve.

A map of the journey

Until very recently, most models of human behaviour in the policy discourse have been based on an overly simplistic view of human behaviour originating from economics[4,10–12]. Economics is a science of understanding system-level features such as patterns of production and consumption as reflected in relative prices that emerge from decentralized decision-making. In this respect, the discipline was a very early innovator in self-organizing systems going back to Smith's invisible hand, and Hayek's emphasis on decentralized information processing—aggregate patterns emerge from individuals' actions, and those individuals in turn respond to these aggregate patterns[13]. However, what economics has lacked is to capture the diversity of human behaviour in its models, at least since its mathematization which drove the need for (over)simplification. Even though the inadequacy of current models of human behaviour has been highlighted many times[12,14], there are still no recognizable humans in standard economic models, including most

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work in environmental and resource economics[11]. Rather, there are self-interested, perfectly disciplined rational economic agents ('econs', also known as *Homo economicus*), represented by identical algorithms that solve specific optimization problems under a set of specific constraints that bear little resemblance to anything that could be called 'human' behaviour. Our goal here is to explore key elements of a better understanding of human behaviour, to replace these deterministic information processing econs (hereafter we use the term mechanistic to refer to this model of human behaviour) with richer conceptualizations of human agents within the context of self-organizing CAS in which we live.

The social sciences have generated a large body of knowledge relevant for our endeavour. First—moving from 'econs' to humans—we reflect on insights that have led to the recognition that people are diverse and intrinsically pro-social, do not always act on their plans, and are generally not well described as optimization algorithms. We thereby draw on the bulk of work in cognitive psychology and behavioural economics to date on singular, 'quasi-rational' individuals acting and making decisions in relative isolation, through interactions with their immediate contexts[12]. Although this first step is not intrinsic to a CAS perspective, it is an essential building block for our journey as it provides a richer representation of the key system component—the human decision-maker.

Next, building on step one, we place individuals in their multiple broader contexts, and highlight relevant insights about the more 'durable' influences of different socio–cultural and biophysical contexts on individuals' behaviour as well as their interactions with others and their environments. We here combine insights not only from social, environmental and cultural psychology, as well as cultural sociology, but also from sustainability science, postulating the need to move beyond the model of a mechanistic, 'quasi-rational' to an adaptable 'enculturated'[12] and further to an 'enearthed' actor.

In the final step, we argue the need to view human behaviour as dynamic and co-evolving with its social–ecological contexts across local to global scales. We conclude our journey with reflections on implications for policy and research frontiers.

From 'econs' to humans

Homo economicus is the dominant model of human behaviour in economics, but also widespread in other social sciences and research fields[11,12,15], including natural resource management[10]. It is a selfish and infinitely capable entity that has perfect information, including probabilities of future events, about all other agents and aspects of the system in which it operates. It has an internal, fixed 'utility function' that maps all possible outcomes to an ordered list. And it has the computational power to choose an asset allocation that achieves the highest value on this list and does so without tiring and remorse. These characteristics come with the advantage of analytical clarity and tractability, which is one of the reasons why many scholars across disciplines continue to fall back on this model.

Behavioural economics has emerged through a stepwise process of relaxing the assumptions of unbounded rationality, self-interest and will-power of *Homo economicus*[16]. The bulk of work to date in this field (also described as the "first strand of behavioural economics"[12]) systematically explores when and how human behaviour differs from *Homo economicus*. Examples of such deviations and their implications for different applications have been reviewed by others[16–18]. Here we extend these ideas further and will begin by highlighting relevant insights for sustainability in the Anthropocene.

Humans are not optimization algorithms. It was by the early 1950s that economist and political scientist Simon pointed out that our cognitive capacities are limited, restricting our capacity for 'utility maximization'[19]. It was shown soon thereafter that cognitive limitations are widespread and influence economic decision-making. By the 1990s, there was plenty of evidence that bounded rationality, if incorporated into models, could lead to better predictions[14].

Limited cognitive capacities are particularly important to consider in the context of environmental change, which requires decision-making under uncertainty. Cognitive psychologists Kahneman and Tversky have shown that we struggle with interpreting probabilistic representations of uncertainty. As a result, they proposed prospect theory[20], an empirically based alternative to the expected utility framework. Similar work suggests that people generally choose 'measurable uncertainties', where probabilities and outcomes are known, over ambiguity[21]. Yet, all these elaborations and extensions still assume that humans process probabilities like a computing device.

Research reflecting how people actually cope with uncertainty also highlights our use of fast and frugal heuristics[15]. In the early 2000s, psychologists proposed the concept 'risk as feelings', which suggests that it is difficult for humans to deal with probabilities when strong feelings are involved and that we are more inclined to take actions and respond to risk when we learn from experience rather than description[22].

Another important theme is the inability (as citizens and policymakers) to consistently compare outcomes (uncertain or not) across large time periods. This is especially important for environmental policies as costs and benefits are often separated by large time periods and can explain why climate change policies can meet strong opposition as their benefits are not clear cut and visible in the near future[18].

Humans do not always act on their plans. Models of human behaviour and policy design must also consider that we have limited self-control. Philosophers and social scientists have long pointed out the weakness of our will. Hume suggested, for example, that imperfect self-control is one of three reasons why societies need government[23].

Imagine two different 'selves' of a person struggling between a 'myopic doer' and a 'farsighted planner'[24]. This struggle may lead to time-inconsistent decisions where near-term outcomes get disproportionate weight because our future self, due to limited self-control, will not follow through. Procrastination on climate change action is a glaring example of such time-inconsistent decision-making[18].

'Status quo bias'[25] is another side of the same coin which suggests that 'mental inertia' impacts our decisions. Limited cognitive capacities and lack of self-control can make sustainability issues sticky but may also be exploited to improve environmental outcomes[18], one example being the 'default nudge'[26] which plays on mental inertia.

Humans are intrinsically pro-social. Voluntary blood donations and charitable giving are examples of limited self-interest. Lab, field and functional magnetic resonance imaging (fMRI) experiments show that when making decisions we take much more into account than direct material benefits to ourselves[27–29]. For example, we value fairness[30], but may also sacrifice personal well-being to harm others[27]. Some neuroscientists even claim that "our brains are wired to connect"[28].

Bounded self-interest can also explain why cooperation can be facilitated through non-binding communication ('cheap talk'), by making it easier for conditional co-operators to identify other co-operators and by enabling a sense of group identity and trust[29]. Based on these insights, political economist Ostrom advocated for an empirically grounded theory of collective action with reciprocity, reputation and trust as core features[29]. In a similar line of thought, the fact that most of us are conditional co-operators (we co-operate as long as others do so[31]) and altruistic punishers (we punish norm violators), lead others to propose a theory of 'strong reciprocity'[27]. Some even refer to co-operators as a phenotype[32].

Individual behaviour in context

The work summarized above—from 'econs' to humans (Fig. 1a), has certainly improved our understanding of individual behaviour;

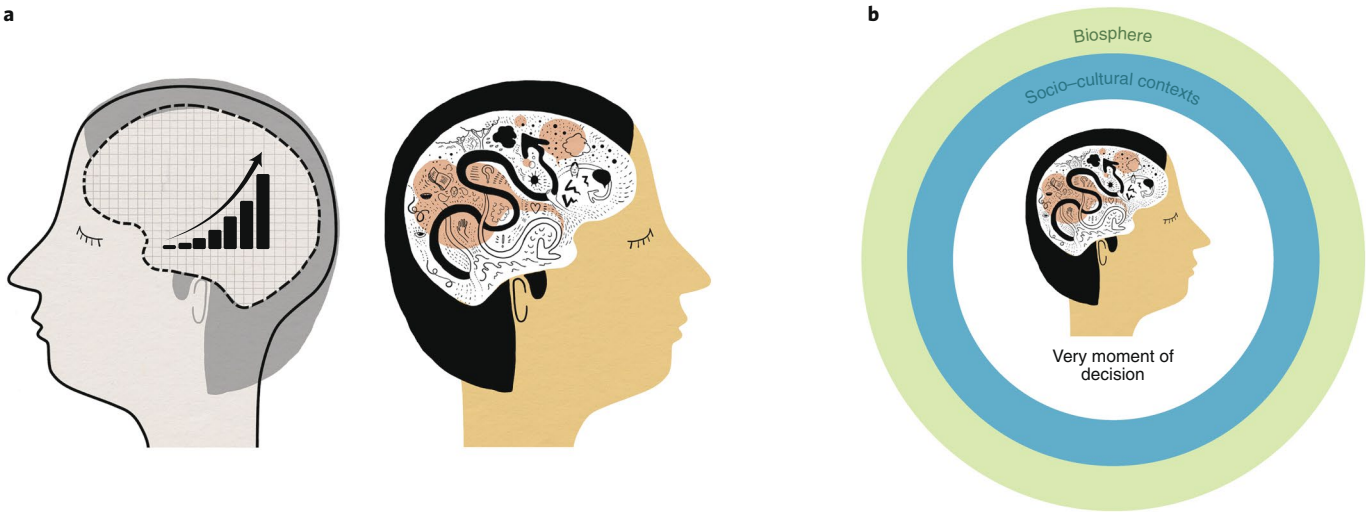

Fig. 1 | From 'econs' to humans as 'enculturated' and 'enearthed'. a, The first step of our journey towards a dynamic understanding of human behaviour—from 'econs' to humans. In this step, we replace *Homo economicus* (or 'econ', left) with a model of human behaviour that represents individuals as diverse and intrinsically pro-social, recognizes that people do not always act on their plans, and are generally not well described as optimization algorithms (right). In this model, singular individuals act and make decisions through interactions with their immediate contexts. **b**, The second step of our journey—individual behaviour in context. In this step, we go beyond the immediate contexts of the 'very moment' in which individuals take their decisions and place ('quasi-rational') individuals in their multiple broader socio-cultural contexts (humans as 'enculturated'), ultimately embedded within the biosphere (humans as 'enearthed'). Head illustrations: Elsa Wikander/Azote.

specifically, in relation to its immediate situation or contexts[33]. That is the 'very moment' in which decisions are made[12]. This line of work has mostly focused on universal cognitive processes as the main determinant of behaviour. However, as we will highlight below, building on this foundation, broader and more 'durable' contextual influences can significantly influence behaviour in different ways (Fig. 1b). That is, to regard humans as 'enculturated' and 'enearthed'.

Humans are socially and culturally wired. Individuals' broader cultural contexts and the social groups they belong to strongly influence their behaviour. This is what we mean by 'enculturated'. Regarding the influence of cultural context, relevant work can be found in cultural and cross-cultural psychology, which started to grow in the 1980s[34–36]. For example, Triandis' early work offered evidence of culture-specific influences on thought and action in relation to whether individualism or collectivism characterizes a culture[37]. Whereas in individualistic cultures (for example, United States or Western Europe) personal considerations and internal processes are more commonly predictors for individual behaviour, in collectivistic cultures (for example, East Asia and many traditional cultures), behavioural predictors are more commonly to be found in considerations of others and the external environment[34]. In a similar vein, individualistic cultures tend to foster an 'independent' understanding of 'the self' and a more analytical system of thought, whereas collectivistic cultures tend to foster an 'interdependent' understanding of the self and a more holistic system of thought[36,38].

Today, a large body of work explores how profoundly cultural contexts can shape our cognitive processes[36,38], emotions[36] and values[39], and consequently behaviour in general, and pro-environmental behaviours in particular[40]. This cultural variation strongly contrasts what has been previously thought to be universal[33].

In the early 2000s, this understanding also started to enter behavioural and experimental economics with the seminal paper led by cultural anthropologist Henrich[41]. This study raised the awareness that behaviour is diverse and varies strongly across cultural and socio–economic contexts, reflecting institutions that have co-evolved over time[41]. Later studies by behavioural economists, focusing on human cooperation among small-scale agriculturalists or fishers[42–44] corroborate that culture, including socio–economic contexts, considerably influences behaviour.

Within their broader cultural contexts, individuals also belong to different cross-cutting social groups (for example, gender or social class). Studies in cultural sociology and psychology have established that such groups provide individuals with specific schemas and mental models that provide 'cultural repertoires' of habits, skills and styles[45]. These cultural repertoires, in turn, shape more universal cognitive processes[46]. They do not prescribe but rather enable or constrain behavioural patterns[46]. Social groups come with their specific norms and rules. Social norms, which can be defined as "behavioural rules and standards […] that are transmitted culturally"[47], play a critical role in any social group, or larger society, as they shape our expectations by defining what is right, wrong and fair[48]. They have been particularly highlighted in recent years to either aid or obstruct sustainability[47,49].

We are all part of the biosphere. Irrespective of where we live and how we earn our living, we are embedded in the biosphere and our actions and overall well-being intimately depend on the biosphere[9]. This is what we mean by 'enearthed'.

The biosphere connection is very close for small-scale pastoralists or fishers in the sense that they directly depend on local ecosystems. Their actions (for example, resource extraction and land-use decisions) have a more immediate and direct effect on the very same ecosystem. Experimental work comparing individual and collective behaviour of different resource user groups highlights that within the same cultural context (for example, shared national identity, ethnicity and language) cognitive and behavioural differences can occur depending on people's past experiences of social interdependencies and cooperative activities, which, in turn, depend on the specific subsistence activity and the specific ecological environment[43,44,50,51].

Others may have fewer direct interactions with ecosystems, but are still 'embedded in a place'[52] and inextricably interwoven with all biophysical cycles and processes, and crucially dependent on the biosphere, for example, obviously for food and air but also for mental well-being. Their lack of interaction with nature in situ can, in fact, have profound negative impacts on their physical, mental and

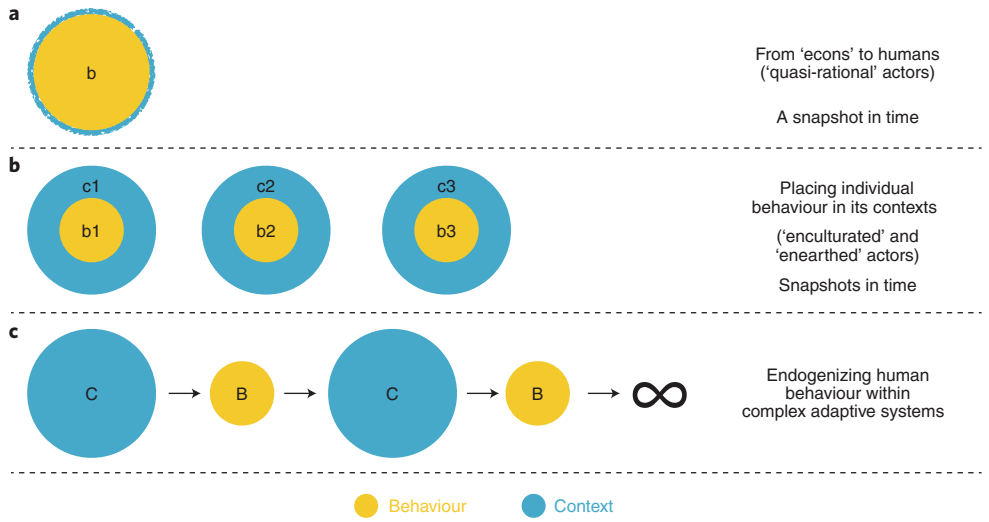

Fig. 2 | Different conceptualizations of interactions between human behaviour and context. a, Behaviour (b) can be significantly influenced by the immediate context of the very moment in which decisions are made (narrow blue ring). This conceptualization represents behavioural work in which context is treated only marginally (see 'From 'econs' to humans' section). **b**, Behaviour (b1–b3) can be significantly influenced by broader, more durable contexts (c1–c3). This conceptualization represents work that places individual behaviour in its broader contexts, beyond 'the very moment of decision'. Contexts contain both socio-cultural and biophysical elements (see 'Individual behaviour in context' section, and Fig. 1b). Panels **a** and **b** represent snapshots in time and one-way interactions from context to behaviour. **c**, A CAS perspective on human behaviour, linking behaviour and contexts and capturing their interplay over time, that is, two-way interactions. B, set of behaviours; C, set of contexts.

cognitive health and well-being[53]. There is also evidence that a lack of nature experiences can discourage positive emotions, attitudes and behaviour towards the environment[54].

So far, we have gathered a plethora of evidence on the critical role that different contexts—from the very moment of decision to broader socio–cultural and ecological contexts—play for human behaviour. Next, we will outline how understanding human behaviour as part of CAS helps us link these bodies of work, that is, combine the notions of 'quasi-rational', 'enculturated' and 'enearthed', as well as capture the dynamic interplay between behaviour of individuals and their contexts. That is, to understand human behaviour as shaping and being shaped by its contexts.

Human behaviour as part of CAS

We picture the journey towards an understanding of human behaviour as part of CAS in three steps (Fig. 2):

1. From 'econs' to humans (Fig. 2a): recognize that humans and their behaviour (b) are diverse and not well described by optimization algorithms. Behaviour can be significantly influenced by the immediate context of the very moment in which decisions are made (the narrow blue ring).
2. Placing individual behaviour in its contexts (Fig. 2b): move beyond 'the very moment of decision' to study human behaviour in broader contexts. Such contexts extend more 'durable' influences (thicker blue rings) on behaviour leading to context-specific behaviours (for example, b1 for c1, b2 for c2 and so on). Note that Fig. 2a and Fig. 2b are snapshots in time.
3. Endogenizing human behaviour within CAS (Fig. 2c): Acknowledge that fully endogenizing human behaviour within CAS requires moving beyond snapshots in time, and instead recognize human behaviour and its contexts as ever-evolving and influencing each other (a set of contexts (C) leads to a set of behaviours (B), which in turn creates a new set of contexts (C), and so on). In this case, elements of a certain context exist only for a certain amount of time, in a particular place, as behaviours create a new set of contexts, and so on.

Figure 2 highlights that moving towards a dynamic understanding of human behaviour fundamentally rests on the insights of the bodies of work outlined in this paper. There is substantial knowledge about the first two steps (Fig. 2a,b). Much less is known about the third step (Fig. 2c). Here, we build on the first two steps to explain the third, while reflecting on the dynamics of human behaviour in the Anthropocene.

To explain the third step, we make use of Fig. 3, which is a deeper exploration of Fig. 2c. It illustrates the progression of ideas from identical interacting algorithms ('econs' or *Homo economicus*, Fig. 3a) to diverse interacting humans in CAS (Fig. 3f). Whereas Fig. 2c is our attempt to capture the temporal dynamics between behaviour and context, Fig. 3d–f illustrates how this process of change may unfold.

Figure 3a represents interacting econs (*Homo economicus*) using identical and fixed decision-making protocols. In standard economic models, one assumes that these actors use local information (for example, prices or actions of others) to move toward an equilibrium (for example, a general equilibrium or Nash equilibrium). In this respect, they are self-organizing adaptive systems where 'adaptive' simply means the process of moving toward an equilibrium. Figure 3b illustrates a richer conceptualization of 'quasi-rational' actors: interacting diverse actors responding and adapting to their immediate contexts. Figure 3c extends Fig. 3b to include broader and more 'durable' contextual changes ('enculturated' and 'enearthed'). Figure 3d–f adds the CAS approach where local interactions lead to higher-level emergent structures, that is, individuals create contexts (Fig. 3d), which feedback to behaviour (Fig. 3e), creating a feedback between context and behaviour (Fig. 3f).

The contexts created by the interactions among individuals include social networks, norms and rules, culture, technologies, and ecologies. These contexts can be classified in different scales and levels like many governance systems[55], operate in complex networks like financial and communication systems[56], or result from the reorganization of ecological or Earth systems[1]. Hence, the emphasis on capturing human behaviour as both 'enculturated' and 'enearthed'.

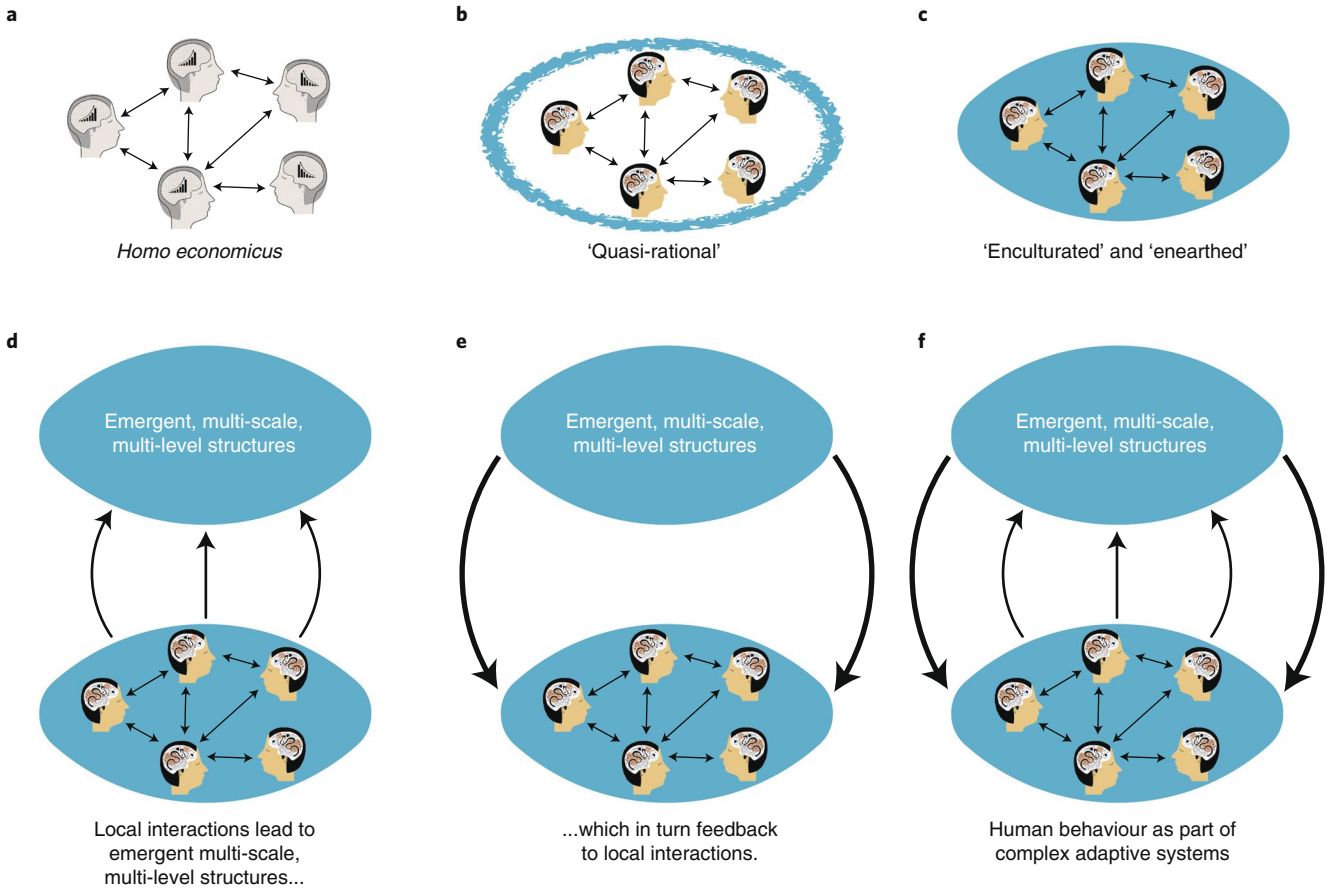

Fig. 3 | From *Homo economicus* to regarding human behaviour as part of CAS. a, Interacting identical algorithms (*Homo economicus*). **b**, Diverse interacting 'quasi-rational' actors affected by immediate contexts (see also Fig. 2a). **c**, Diverse interacting 'enculturated' and 'enearthed' actors (see also Fig. 2b). **d**–**f**, A three-part sequence of how to endogenize human behaviour within CAS: local interactions of individuals with their contexts lead to multi-level, multi-scale emergent structures (**d**), which in turn feedback to local interactions (**e**). **f**, Human behaviour as part of a CAS: local interactions lead to emergent patterns at higher levels and different scales, which in turn feedback to lower levels, and so on (see also Fig. 2c). Please note that **d**–**f** are not meant to suggest a strict temporal sequence but rather steps in a continuous co-evolutionary process. Head illustrations: Elsa Wikander/Azote.

From a CAS perspective, 'enculturated' means the dynamic interplay between people creating culture shaping people in a continuous process. Several scholars have stressed that culture and the self "are most productively analysed together"[57], as individuals are not only shaped by culture but also shape culture[33]. However, such dynamic views on culture and the self and the importance of broader cultural influences, have not yet received much empirical attention[33]. Two exceptions are the work on 'culture cycles'[57] and cultural evolution[58,59]. Culture cycles describe an ongoing process by which the actions of individuals create the socio–cultural contexts to which they later adapt, and those contexts, in turn, shape human actions in a way that their actions perpetuate these contexts[57], hence, a CAS (Fig. 3d–f).

A CAS perspective can also be used to shed light on the increasing disengagement from nature highlighted in the 'We are all part of the biosphere' section. Direct nature experiences become increasingly scarce to new generations, creating an ever-narrowing spectrum of nature experiences. An 'environmental generational amnesia' emerges stemming from each generation's reduced nature experiences, shifting the baseline of reference points[54]. This is an example of an emergent phenomenon, where context shapes attitudes and behaviour toward nature, which in turn shapes nature.

A CAS lens on human behaviour also forces us to recognize that behaviour and contexts shape each other continuously across various spatial and temporal scales. Take dietary patterns for example. In the past, local ecological conditions interacted with local social and cultural conditions which led to the emergence of certain traditional local and regional diets (for example, the Mediterranean diet or African diets). Some of these regional diets still exist today but with increasing specialization, trade and cultural transmission, we are now witnessing the emergence of a new 'global' diet. This diet, rich in animal protein and added sugar does not only threaten human health but also biosphere integrity[60]. This example illustrates that the impacts of our behaviours now operate at the scale of the biosphere and may generate more frequent, surprising feedbacks from higher-level emergent structures. A CAS approach can also capture non-linear interactions, and slow and fast variables (some contextual changes may be slower than others), which can generate multiple attractors, and regime shifts, such as large-scale behavioural tipping or major shifts in social norms. The latter could be of great significance for large-scale sustainability challenges[49].

As the example of an emergent global diet highlights, an important dimension of human behaviour in relation to its broader contexts concerns cultural transmission across generations. Humans learn norms, values, ideas, technologies and other cultural elements from each other, and some of these are transmitted more than others, resulting in a selection of specific behavioural patterns. These cultural transmissions can occur at different levels, with the

group level as a likely important one, where cultural group selection, multi-level selection or intergroup competition could be key processes[47,59,61]. Through the ability of groups to socially interconnect and learn from one another, cultural evolution has generated collectively held moral sentiments and meanings, which serve as foundations from which formal and informal institutions have emerged[27,62,63]. The higher-level 'attractors' range from meanings guiding individual and group behaviour to guiding principles for behaviour such as the 'golden rule' of treating others the way you want to be treated, which is found in many cultures and religions, or the United Nations declaration of human rights. Such 'collective imaginaries'[64] or 'imagined orders' (networks of shared stories, or inter-subjective realities, that become 'real' by virtue of the fact that they are collectively agreed upon)[65] have historically profoundly shaped human interactions and also influence the way we interact with the biosphere and hence, are powerful in shaping outcomes for sustainability.

Policy implications and research frontiers

The following sections highlight some implications that a CAS perspective has for how we think about policy and future research.

Expanding the policy space. Consider the differing (or even opposing) explanations provided by social scientists as to why many poor African–Americans did not evacuate before Hurricane Katrina hit the Gulf Coast in 2005 (as highlighted by Markus and Conner in ref. [66]):

"Of course they didn't leave, said the psychologists, because poor people have an external locus of control, low intrinsic motivation, or low self-efficacy. Of course they didn't leave, said the sociologists and political scientists, because their cumulative lack of access to adequate income, banking, education, transportation, healthcare, police protection, and basic civil rights makes staying put their only option. Of course they didn't leave, said the anthropologists, because their kin networks, religious faith, and historical ties held them there. Of course they didn't leave, said the economists, because they didn't have the material resources, knowledge, or financial incentives to get out."[66]

This example highlights not only the different explanations of human behaviour within different disciplines, but also hints at the different policy advice that each would provide. Each perspective contributes to better understanding (a particular aspect of) human behaviour. However, what seems to be lacking is an approach that can simultaneously capture the notions of human behaviour as 'enculturated' and 'enearthed', and the dynamic interplay between human behaviour and its broader more 'durable' contexts. We argue for a new framework that does not only take us beyond marginal extensions of the simplistic and mechanistic models of human behaviour that dominate much of the environmental policy discourse to date, but also embraces the fact that we dynamically create socio–cultural and environmental contexts that coevolve with our behaviour (Fig. 3d–f). CAS provides such a framework.

In stark contrast to the mechanistic approach in which a policy is intended to change incentives (or restrictions) operating on individuals with a fixed set of preferences and in an environment with a fixed structure, a CAS perspective would focus on how policies create contexts and influence their change over time and space. Hence, our lens implies that rather than focusing on prescribing specific policies (such as a carbon tax) in the vein of 'one instrument per problem' thinking, focus should be placed on policies that support contexts that serve as 'attractors' guiding human actions and relations. For example, the use of systemic metaphors in public discourse highlighting our dependence on and embeddedness within the biosphere (such as "the Earth is our home")[67] may help shift 'imagined orders' into a more commons-based approach rather than constraining policy to market or state solutions. Another example is for policy to create contexts that enable and support a diversity of solutions to emerge from local initiatives. Both these examples highlight the need for considering longer time scales. It is important to note that our suggested approach to policy does not necessarily exclude the use of conventional policies. However, when such policies are implemented, we argue for a note of caution and the need to carefully consider broader contexts and longer-term influences.

Our suggested approach to policy is based on insights across multiple fields and disciplines and thus more inclusive. It therefore also moves beyond the promising recent developments in policy design to integrate behavioural insights[4], which are so far overly reliant on work based on the 'quasi-rational' actor[12,46], and hence, miss out on the integration of insights around the notions of 'enculturated' and 'enearthed'. Such an approach would also be better suited to account for emergent unintended consequences, surprise and true uncertainties—all prominent characteristics of the Anthropocene and that a CAS perspective embraces[68].

The interplay between more realistic models of human behaviour, the emphasis on context, and suitable research tools and techniques (see 'Research frontiers' section) may expand the possibilities for policy design. However, the gap between current approaches informing policy and the approach that we propose is huge. It is therefore high time to start filling this gap with emerging insights on human behaviour across different research fields and disciplines but also with new interdisciplinary collaborations that could help transformations towards sustainability.

Research frontiers. A critical research challenge is to understand how contexts are generated, maintained and dissolved over time, and how individual behaviour shapes and is shaped by context. In particular, how contexts in favour of sustainability emerge and which mechanisms or 'selection processes' are key for sustainability. Concepts and theories from literature that outline potential mechanisms for cultural change could be promising for this endeavour, such as the field of cultural evolution[58]. As highlighted above, group-level selection could be one key process that shapes contexts and thus individual behaviour at the meso-level, that is, between groups[59,61]. This is an important area for future research.

It is important to note that not all actors have the same ability, or power, to contribute to emerging structures or to respond to undesirable structures. Diversity also includes the differing weights individuals have in shaping emergent outcomes (whether they are conscious of it or not), or in their ability to counteract emerging structures. This is another critical research frontier to better understand the emergence of sustainable and just pathways.

More studies are needed to investigate behavioural differences across different contexts to better understand how environmental and socio–cultural aspects of context interrelate to produce different effects on behaviour—and different conditions for sustainability interventions. Most behavioural studies and, hence, psychological understanding, are still overly reliant on laboratory studies with participants from western, educated, industrialized, rich and democratic (W.E.I.R.D.) countries—a fraction of the human population[69]. Furthermore, research designs that allow for the study of behavioural change over time will be indispensable. Databases like the World Value Survey offers insights about geographical diversity and long-term trends of values and attitudes[39]. But few behavioural studies take a long-term or even dynamic perspective.

Given the daunting challenge of studying the interplay between diverse interacting humans and the broader contexts they create over longer time horizons, formal models play a key role in future research. Experiments in silico with multi-agent systems are foundational to complexity science and critical for characterizing possible multi-level structures that may emerge in CAS and how they feedback to agent behaviour. There is a considerable body of work in this area, typically under the label of agent-based modelling

(ABM). However, such studies are often either highly conceptual or very case specific. They also vary significantly in the degree to which they build on theories of human behaviour[10,70]. We therefore propose a multi-method approach, which includes classes of ABM grounded in theory, experimental and empirical evidence, being able to better reflect the diversity of human behaviour within different contexts.

A CAS approach also opens up spaces for new research collaborations, combining 'conventional' behavioural studies with approaches that have a contrasting perspective on human action. For example, through a focus on the dynamic co-evolution of human behaviour within temporally unfolding socio–cultural and material contexts, a CAS approach provides fertile ground for interdisciplinary collaboration with poststructuralist accounts of human action such as social practice theory[71,72]. Hence, our approach invites scholars to build bridges between opposing paradigms and to explore complementarities.

Received: 9 March 2019; Accepted: 8 October 2019;
Published online: 25 November 2019

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Acknowledgements

This Perspective is a product of a series of Behaviour, Economics and Nature (BEN) workshops hosted by the Beijer Institute of Ecological Economics at the Royal Swedish Academy of Sciences. The work has been funded by the Kjell and Märta Beijer Foundation, and the Marianne and Marcus Wallenberg Foundation. We would like to thank S. West and D. Ospina for insightful comments and suggestions on previous drafts.

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C.S., J.M.A., T.L., C.F. and S.P. conceived the idea with input from J.C.C., A.-S.C., M.A.J., J.N. and M.S. C.S., J.M.A. and T.L. led the writing process with input from C.F., S.P., J.C.C., A.-S.C., M.A.J., J.N. and M.S. C.S. and T.L. led the revision with input from J.M.A., C.F., S.P., J.C.C., A.-S.C., M.A.J., J.N. and M.S.

Competing interests

The authors declare no competing interests.

Additional information

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