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Provisioning Systems for a Good Life within Planetary Boundaries

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Abstract

The concept of provisioning systems has recently emerged as a promising way to understand the differences between levels of resource use and social outcomes observed across societies. However, the characteristics of provisioning systems remain poorly understood. Here, we make a new contribution to conceptualising provisioning systems and to understanding differences in the resource efficiency with which they achieve social outcomes. We define a provisioning system as a set of related elements that work together in the transformation of resources to satisfy a foreseen human need. We analyse six theories in terms of their contribution to understanding provisioning systems within the biophysical and social constraints of Raworth's "Safe and Just Space" framework. We find that most of these theories fail to prioritise human needs and well-being, and do not incorporate explicit environmental limits. However, they provide important insights that we draw upon to identify six important provisioning system elements (households, markets, the commons, the state, techniques, and material stocks). Based on the theories, we also identify two important relationships between elements, namely feedbacks and power relations. We further propose the concept of "appropriating systems" as a component of provisioning systems. Appropriating systems reduce the resource efficiency of human well-being via rent extraction, and act as a barrier to meeting human needs at a sustainable level of resource use. We combine these concepts into a new framework, and discuss applications to energy systems.

Keywords

Safe and Just Space; Planetary Boundaries; Provisioning Systems; Appropriating Systems; Human Needs.

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1. Introduction

There is an urgent need to find ways to guide societies towards the twin priorities of meeting human needs and safeguarding the planet's life-support systems. The "safe and just space" (SJS) framework created by Kate Raworth (2012, 2017a) provides a useful starting point. It combines the concept of planetary boundaries for Earth-system stability (Rockström et al., 2009; Steffen et al., 2015) with the complementary concept of social boundaries, which have been linked to the Sustainable Development Goals (UNGA, 2015; Raworth, 2017b). The SJS framework argues that development should occur within a doughnut-shaped space where resource use is below the level that carries a substantial risk of crossing planetary boundaries (i.e. a "safe" space), but above the level required to meet people's basic needs (i.e. a "just" space).

The SJS framework is useful because it gives a clear, visual assessment of whether a given society's resource use overshoots sustainability goals, and whether the society falls short on achieving established social goals, without losing the perspective that all these goals are connected (see Figure 1). The Doughnut can be seen as a valuable compass that points in the direction that a society needs to head, but as Raworth (2017b, p. e49) notes, "the greater task is to create an effective map of the terrain ahead."

Our aim here is to assist with this task through an analysis of theories that strive to open up the "black box" between resource use and social outcomes. We conduct this analysis to develop the emerging concept of "provisioning systems". This concept aims to provide insight into why levels of resource use and social outcomes vary across different societies (e.g. Brand-Correa and Steinberger, 2017; O'Neill et al., 2018).

O'Neill et al. (2018) suggest that provisioning systems can be understood as interlinked complex physical and social systems that mediate the ways in which resources are extracted and transformed into the material and cultural things that contribute to needs satisfaction. Physical elements of provisioning systems include networks of physical infrastructure, technologies and their efficiencies, whereas social elements of provisioning systems include government institutions, communities, and markets. The authors assert that some societies transform resources into the things people need more efficiently than others due, at least in part, to differences in the physical and social provisioning systems that satisfy those needs.

However, the general characteristics of provisioning systems remain poorly defined. Here, we attempt to provide some clarification by asking: what are provisioning systems, and how can we understand the ways in which they generate different social outcomes at different levels of resource use? To inform our investigation, we analyse six established theories that can help us understand how provisioning systems mediate the relationships between biophysical resource use and social outcomes in the context of limits. Following Sovacool and Hess (2017), our use of the term *theory* includes any theoretical construct, conceptual framework, heuristic device, model or approach that is relevant, in our case, to understanding the links between resource use and well-being. We recognise that the term *theory* is regularly used in the social sciences to express quite different things, without claiming that any single meaning is "true" [see Abend (2008) for a detailed and persuasive call for such semantic pluralism].

The theories that we analyse include (i) Complex Adaptive Systems, (ii) the Multilevel Perspective on transitions, (iii) the Social–Ecological Systems Framework, (iv) the Social Provisioning Perspective, (v) the Systems of Provision approach, and (vi) Theories of Practice. Their unifying characteristic is that they all investigate the type of interconnected, complex behaviour that O'Neill et al. (2018) describe for provisioning systems. We analyse each theory based on five criteria to help identify insights into

why some provisioning systems may be more resource-efficient than others. Three of the criteria analyse the theories in terms of key features drawn from systems thinking, namely their scope, the core elements and relationships that they consider, and their vision of how change happens. The other two criteria evaluate the theories in terms of the core requirements of the SJS framework, namely sustainable resource use and sufficient social outcomes.

Following our analysis, we bring together two broad groups of provisioning elements and their interconnections to guide analyses of why resource use may differ across societies, and understand how to overcome conflicting purposes that block efforts to achieve desirable change. Notably, we argue that O'Neill et al.'s (2018) explicit focus on needs satisfaction does not adequately capture resources that are used for other purposes, such as rent extraction by a wealthy global elite. We propose the concept of "appropriating systems" to fill this gap.

The remainder of this article is structured as follows: Section 2 reviews literature on the SJS framework and provisioning systems, and proposes a formal definition for the latter. Section 3 briefly describes the six theories. Section 4 analyses each theory with respect to three criteria drawn from systems thinking, while Section 5 analyses the relevance of the theories to the two main aspects of the SJS framework. Section 6 argues that no single theory can guide societies towards the goal of a good life for all within planetary boundaries, and identifies provisioning elements, key relationships, and conflicting purposes drawn from our analysis. It proposes the new concept of appropriating systems, integrates these insights into a general analytic framework, and illustrates potential applications. Section 7 concludes.

2. Integrating the Safe and Just Space and Provisioning Systems

In this section, we conduct a brief review of literature on the SJS framework and provisioning systems (Section 2.1), and propose a formal definition of provisioning systems (Section 2.2).

2.1 The Safe and Just Space Framework

The SJS framework starts with the "nested" vision of sustainable development, where economic activity occurs within human society, which is embedded within the Earth-system (Boulding, 1966; Daly, 1973; Folke et al., 2016; Griggs et al., 2013). The framework asserts that the overarching goal of societies should be to "meet the needs of all within the means of the planet" (Raworth, 2017a, p. 10). It communicates progress towards this goal via a single, intuitive diagram (Figure 1).

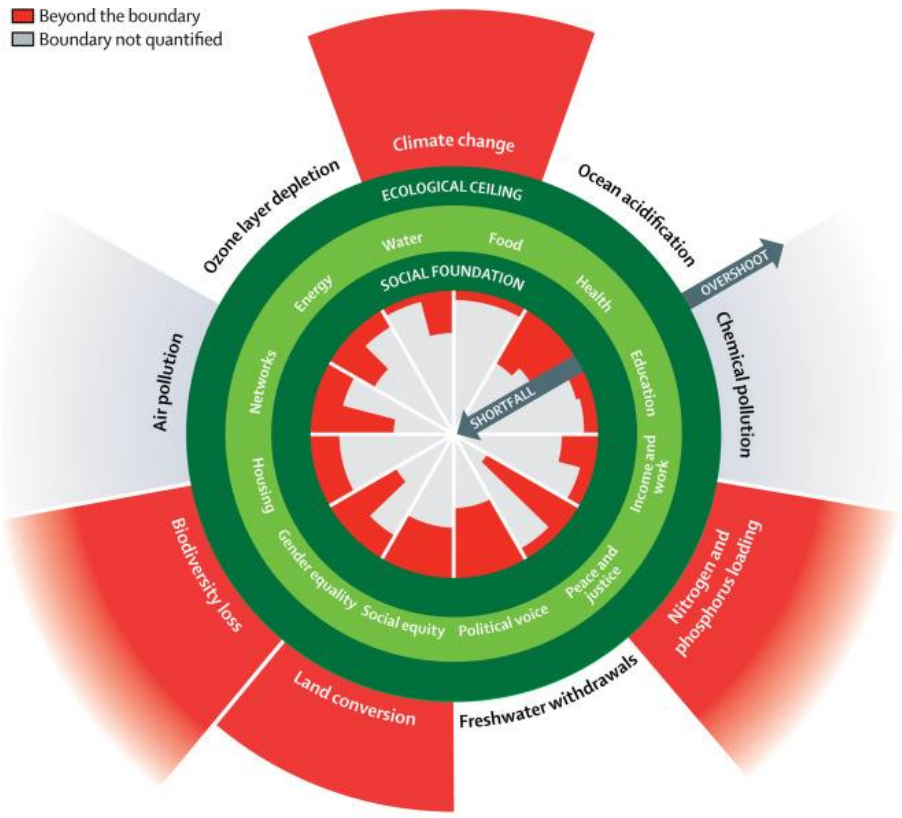

Figure 1. The Safe and Just Space framework (a.k.a. the "Doughnut"), showing shortfalls in meeting human needs (below the social foundation) and overshoot in planetary boundaries (above the ecological ceiling) at the global level. Source: Reproduced from Raworth (2017b) under a Creative Commons 4.0 license.

A growing number of studies have applied variants of the SJS framework at different scales, including cities (Hoornweg et al., 2016), regions (Cole et al., 2017; Dearing et al., 2014), countries (Cole et al., 2014; Hickel, 2018a; O'Neill et al., 2018; Sayers and Trebeck, 2015), and the world as a whole (Raworth, 2017b). Despite this work, there is still no evidence of any society that is, or has been, operating within the safe and just space. Wealthy societies that achieve most of the social thresholds, such as high levels of life expectancy and education, tend to have levels of environmental pressure (e.g. high CO_2 emissions and nutrient loading) that are far beyond levels that could sustainably be extended to all people. At the same time, poorer societies that stay within planetary boundaries tend to fall short on most of the social thresholds (O'Neill et al., 2018).

O'Neill et al. (2018) propose an analytic framework to understand the links between biophysical resource use and social outcomes in the safe and just space (Figure 2). The framework draws on Daly's (1973) Ends–Means Spectrum, which shows the fundamental dependence of social outcomes on healthy ecosystems and the resources they provide. To define and measure social outcomes, O'Neill et al. (2018) adopt a needs-based approach that sees the satisfaction of a finite set of basic needs, such as nutrition and social support, as a prerequisite for human well-being (Doyal and Gough, 1991; Max-Neef, 1991). This approach argues that basic needs are universal, satiable, and non-substitutable, without denying that the means by which basic needs are satisfied (via "need satisfiers") can vary enormously.

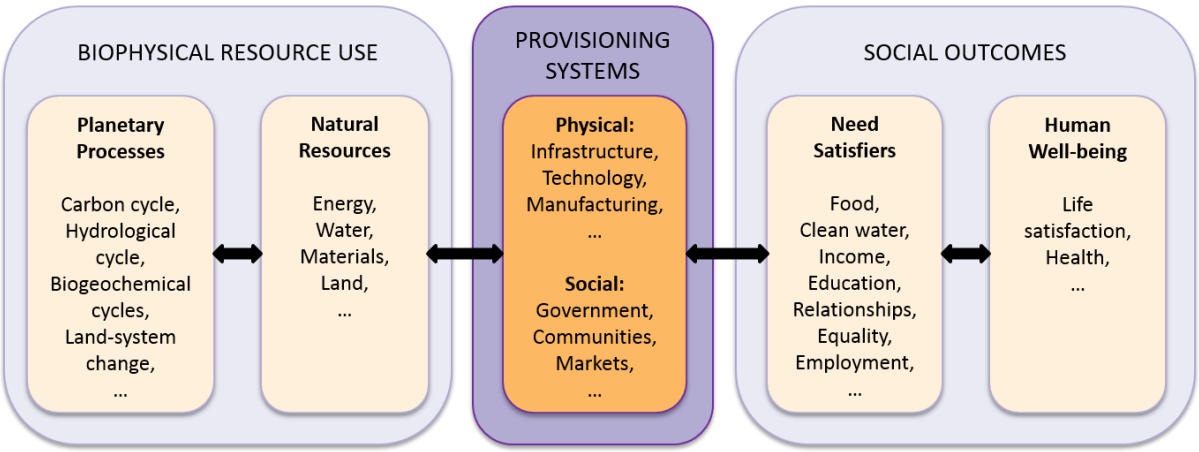

Figure 2. Analytic framework showing the links between planetary processes and human well-being. Provisioning systems are seen to mediate the relationships between biophysical resource use and social outcomes. Source: Adapted from O'Neill et al. (2018).

Importantly, a fundamental dependence on the Earth-system for energy and materials does not imply a strict one-way causal relationship between resource use and social outcomes. Instead, the link between biophysical resource use and social outcomes in O'Neill et al.'s (2018) analytic framework is seen to run both ways, and be mediated by dynamic and complex provisioning systems that can be restructured, intentionally or otherwise (Figure 2). However, the authors do not try to characterise *how* provisioning systems mediate levels of resource use and different social outcomes, noting "this remains a complex challenge for Earth-system researchers going forward" (p. 89). A number of other recent studies make similar statements about the need to better understand provisioning systems (Creutzig et al., 2018; Fanning and O'Neill, 2019; Lamb and Steinberger, 2017; Roberts et al., 2020).

One study (Gough, 2019) makes a useful advance by mapping links between universal human needs, a set of need satisfiers, and their provisioning systems. However, links between biophysical resource use and provisioning systems are not considered. Other studies have investigated the mediating role of provisioning systems between specific types of resource use and needs satisfaction, namely the supply of energy services (Brand-Correa et al., 2018; Brand-Correa and Steinberger, 2017), and carbon-intensive transport (Mattioli, 2016). But it is unclear how these sectoral analyses fit together within the broader scope of sustainability and sufficiency concerns brought together by the SJS framework. Overall, there is still no formal definition of provisioning systems or a broadly applicable approach for how to analyse them, which makes the concept vague from an applied perspective. This article addresses this gap in the literature by exploring what provisioning systems are, and how to analyse them in a manner that is consistent with the SJS framework.

2.2 Defining Provisioning Systems

To make progress towards characterising provisioning systems, it is helpful to consider the terminology in question. "Provision" comes from the Latin *providere*, which combines *pro-* "before" and *-videre* "to see" (Oxford English Dictionary, 2012). It is a versatile term that can be used as a noun or a verb in different contexts that share a common theme of making adequate preparations for an uncertain future.

Likewise, a "system" can be defined generally as a set of related elements that work together to achieve something in a given environment (Meadows, 2009). Thinking in terms of systems represents a way of seeing the world from a holistic perspective that has attracted increasing

attention since the mid-20th century with the founding of general systems theory (Boulding, 1956; von Bertalanffy, 1951). A holistic perspective emphasises the context-specific nature of systems, whereby interconnected elements have a shared history in concrete places over time, which constrains the decisions that can be made in the present.

"Systems thinking" has been defined as a set of related *analytic tools* that work together to identify and understand systems, predict their behaviours, and devise modifications to produce desired effects (Arnold and Wade, 2015). Such a synthesis is needed to understand and manage systems because analysis is reductionist by definition, and the behaviour of a whole system usually cannot be reduced to the sum of its parts.

Building on these definitions and the work of O'Neill et al. (2018), we define a provisioning system as *a set of related elements that work together in the transformation of resources to satisfy a foreseen human need.* In this definition, each need satisfier can be mapped onto a provisioning system that is made up of a set of related elements. That being said, some of these elements may overlap across need satisfiers. For example, the need for adequate nutrition is met through a food provisioning system. However, this system makes use of water supply infrastructure, which also forms part of the sanitation provisioning system. Resources are used to satisfy human needs through a set of provisioning systems made up of interacting ecological, technological, institutional, and social elements. Such systems can (and do) fail to use resources sustainably, and they can also fail to satisfy human needs.

3. Theories for Conceptualising Provisioning Systems

The existing literature provides useful discussions and integrations of different theories to better understand sustainability transitions (Cherp et al., 2018; Fisher et al., 2013; Geels, 2010; Geels et al., 2015; Sovacool and Hess, 2017; Turnheim et al., 2015). However, the existing literature tends to refer to "sustainability" and "well-being" (if the latter is mentioned at all) in general terms (Geels et al., 2015). The assumption tends to be that socio-technical transitions towards cleaner technologies will yield sustainable outcomes, with little attention given to social and environmental limits, or systemic factors, such as rebound effects or burden-shifting via supply chains (Antal and van den Bergh, 2016; Büchs and Koch, 2019; Feola, 2019; Hickel and Kallis, 2019). Our aim is to develop the concept of provisioning systems in the context of explicit limits, namely the planetary boundaries and social thresholds brought together by the SJS framework.

Our analysis of theories for characterising provisioning systems followed a three-step process. First, we identified a long list of 28 theories from the literature. For each one, we combined an analysis of citation counts together with our own expertise to narrow the list down to six theories. While such a list can never be exhaustive, we have endeavoured to select theories that are diverse in their perspectives, and which all aim to provide insight into complex phenomena through a focus on interconnected relationships. The theories include the Complex Adaptive Systems approach, which provides essential insights for conceptualising complex systems; the Social–Ecological Systems Framework, which diagnoses interactions and outcomes in social-ecological systems; the Multilevel Perspective and Theories of Practice, which are the two most-prominent approaches in sustainability research for understanding socio-technical regimes and networks; and the Social Provisioning Perspective and the Systems of Provision approach, which both focus on how economic systems are embedded within a broader social and material context.

Second, we selected five criteria to analyse the theories in terms of (i) their scope, (ii) the elements and relationships they identify, (iii) their vision of how change happens, (iv) their insights on sustainable resource use, and (v) their understanding of sufficient social outcomes. The first two

criteria were chosen based on Meadows' (2009) definition of "systems" (see Section 2.2), while the third was chosen based on the need to achieve transformative systemic changes to live within planetary boundaries (Steffen et al., 2018). The fourth and fifth criteria were chosen based on the core concerns of the SJS framework.

Third, we held a workshop to evaluate the short list of six theories in terms of these five criteria. The workshop was attended by 18 academics working in the broad field of sustainability science with diverse backgrounds that span the natural and social sciences.

In the bulleted list that follows, we provide a very brief description of each theory. Given the huge volume of literature associated with each theory, we refrain from discussing them in more depth here, but instead refer interested readers to recent reviews of the respective literatures (see citations below). Additional detail is also provided in Supplementary Information.

- *Complex Adaptive Systems* theory argues that a complex adaptive system has emergent properties, such as resilience and adaptation, which yield unpredictable and novel behaviour that arises from reinforcing and balancing interactions between its parts (i.e. feedback loops) (Preiser et al., 2018).
- *The Multilevel Perspective* argues that long-term technological changes in the way societal functions are fulfilled (i.e. socio-technical transitions) arise from interactions between three levels, namely the landscape, the incumbent regime, and niche-innovations (Köhler et al., 2019).
- *The Social–Ecological Systems Framework* proposes four interacting sub-systems that affect outcomes in a social–ecological system, namely (i) governance systems, including formal and non-formal rules and norms; (ii) actors; (iii) resource systems, such as a grazing area; and (iv) resource units, such as fodder (Partelow, 2018).
- *The Social Provisioning Perspective* aims to redefine economics as the study of how the provisioning of goods and services in a society is structured in accordance with existing social relations, such as class, gender, and race (Jo, 2011).
- *The Systems of Provision* approach explores how each commodity or service has its own unique political economy that includes everything from resource extraction and distribution to the cultural meanings of consumption (Fine et al., 2018).
- *Theories of Practice* in the field of sustainable consumption refers to a social practice as a routinised collective behaviour composed of three elements, namely (i) materials, such as infrastructure; (ii) competences, such as skills; and (iii) meanings, such as symbolic significance (Corsini et al., 2019).

It is worth noting that there is a difference between the "Systems of Provision approach" and "provisioning systems". The former is a specific theory (as defined above), while the latter is a more general framework (as defined in Section 2.2) for understanding how resources are transformed into human needs.

4. Comparative Analysis of Theories for Understanding Provisioning Systems

In this section, we conduct a comparative analysis of the six theories with respect to the three criteria drawn from systems thinking, namely *scope* (Section 4.1), *core elements and their relationships* (Section 4.2), and *vision of how change happens* (Section 4.3) (see Supplementary Information Table S1 for full results, and the subsections that follow for discussion).

4.1 Scope

Defining the scope of analysis can be controversial because analytic boundaries in space and time often represent an effort to simplify some process to a manageable scale, rather than something

"real" (Meadows, 2009). Overall, none of the theories match the full scope of the analytic framework for provisioning systems (Figure 2), which aims to understand how human needs can be satisfied at sustainable levels of resource use. The Complex Adaptive Systems approach is applicable to a host of ecological and social phenomena, the Systems of Provision approach is tightly focused on interactions along the supply chain of a given good or service, and the remaining four theories fall somewhere in between (Figure 3). We find that the theories with a more general scope offer different ways to think about *how* to analyse provisioning systems (i.e. the "Perspective" box in Figure 3), while the theories with a more specific scope focus on *what* to analyse (i.e. the "Object" box in Figure 3).

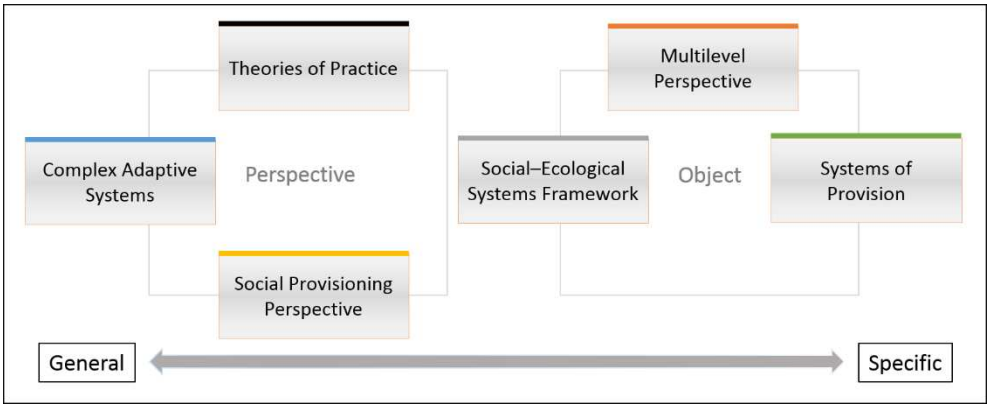

Figure 3. The theories span a range of scopes, from general (left) to specific phenomena (right). They can also be grouped by whether they promote a particular way of thinking to understand different things ("Perspective" box), or whether they identify a particular thing as very important to understand and analyse with different ways of thinking ("Object" box).

Most of the theories describe a given system nested within a surrounding environment, which can form part of a greater system in turn. The exception is Theories of Practice, whose focus on everyday routines leads to a general view of society being made up of a network of emergent practices that lacks an explicit surrounding environment. This perspective of society as an isolated system is problematic for our view of provisioning systems because it is unable to capture the fundamental dependence of human society on the Earth-system.

4.2 Core Elements and Relationships

System behaviour emerges from the interplay between the environment and the three kinds of things that make up a system, namely its elements, relationships, and purpose (Meadows, 2009). In general, system elements tend to be easier to identify than the ways in which they are interrelated. Relationships that amplify changes in a given element (i.e. a reinforcing feedback loop), or those that have a stabilising effect (i.e. a balancing feedback loop), are particularly important for understanding system behaviour (Walker et al., 2012). The comparison of a given provisioning system's overall purpose to satisfy a foreseen human need with the purposes of its elements can help us understand how well the system is behaving, and identify opportunities to use resources more effectively.

Most of the theories identify sets of elements to understand system behaviour that can be placed into an ecological/material group or a social/cultural group (

). The Social–Ecological Systems Framework is the most specific theory we analysed in terms of identifying a long list of potentially related elements, although it does not seek to define specific relationships that govern the outcomes of a given social-ecological system (Schlüter et al., 2014). The Multilevel Perspective is also relatively specific due to its singular focus on socio-technical transitions. Elements include the niche, socio-technical regime, and landscape levels, which are

characterised by increasing degrees of structural stability across technological, social, political, industrial, and cultural dimensions (Geels, 2011). In contrast, Complex Adaptive Systems does not explicitly specify any inherent elements.

In terms of defining types of relationships, all six of the theories share the general systems thinking premise that interactions among elements can create feedbacks and emergent behaviour. The concepts of "resilience", "practices", and "lock-in" all rely on this general notion of interconnections to understand how system behaviour emerges, persists, shifts, or disappears in specific places and time.

Power relations are also recognised to be important across most of the theories. The Social Provisioning Perspective and Systems of Provision are arguably the best-equipped theories to explore specific types of power relations, such as class struggle and gender inequality.

4.3 How Change Happens

Given that no society is currently living within a safe and just space, the question of how change happens is fundamental to understanding whether it is possible to provide a good life for all people within planetary boundaries. The theories analysed in this article draw on a rich body of social science explanations for social phenomena where causation can be placed somewhere on a spectrum between the choices of free individuals (e.g. Hayek, 1952) and the structures that constrain or enable individuals' capacity to act (e.g. Parsons, 1961).

Two of the theories (the Multilevel Perspective and the Social Provisioning Perspective) incorporate some level of causal explanation for system behaviour based on general propositions. In particular, the Multilevel Perspective provides the most explicit discussion of how change happens, including how differences in the timing and nature of niche–regime–landscape interactions can create various transition pathways (Geels and Schot, 2007).

In contrast, two theories (Systems of Provision and Theories of Practice) broadly reject *a priori* explanations, insisting that processes unfold in an entirely context-specific manner. We find some tension in the Complex Adaptive System literature on causality, with some authors asserting it is entirely context-specific (e.g. Schlüter et al., 2019), while others adopt some general propositions on how change happens, such as the adaptive cycle model (e.g. Steffen et al., 2018). The Social–Ecological Systems Framework is not particularly concerned with causal explanations, but rather aims to provide a language and concepts that may be instructive or helpful for others who wish to derive such explanations.

Lastly, the Social Provisioning Perspective and the Systems of Provision approach both draw on heterodox economics explanations of how capitalist societies and context-specific material cultures of consumption change. However, apart from a rejection of the two starting premises of mainstream economics (i.e. that social outcomes are caused by the sum of individual actions, and that economies tend towards equilibrium), explanations of how change happens vary across the heterodox economics traditions (Arnsperger and Varoufakis, 2006; Jo, 2011; Lawson, 2013). For example, Post-Keynesians emphasise how fundamental uncertainty justifies an active role for government to create desired change (Dequech, 2012), while Marxist economists see change driven by the contradictions of capitalist expansion via the appropriation of labour's surplus value, and the commodification of the social and natural world (Fine and Saad-Filho, 2018).

5. Relevance of Theories to the Safe and Just Space Framework

In this section, we analyse each theory with respect to the defining characteristics of Raworth's (2017b) SJS framework, namely sustainable resource use (Section 5.1) and sufficient social outcomes

(Section 5.2). The results are presented in Table 1, and discussed in the subsections that follow. In our analysis, we define sustainable resource use as resource use which is within limits (e.g. downscaled planetary boundaries or local ecological limits). Similarly, we define sufficient social outcomes as achieving minimum thresholds for a set of predefined need satisfiers.

Table 1. Relevance of Theories to Sustainable Resource Use and Sufficient Social Outcomes

Theory	Relevance to Sustainable Resource Use	Relevance to Sufficient Social Outcomes
Complex Adaptive Systems	Highlights general conditions to manage resilience, such as the diversity and connectivity of elements, the duration of delays, and degrees of cooperation. Informs tools that can model scenarios in the context of limits (e.g. planetary boundaries).	Anticipates that policies to improve well-being are often ineffective or produce unanticipated outcomes over time due to feedbacks, adaptive capacities, and emergent system properties (e.g. growth, resilience, collapse).
Multilevel Perspective	Focuses on how "green" technological niche-innovations that use resources more efficiently can break through to achieve widespread adoption, including analysis of the social, institutional, and political factors that foster/impede such adoption.	Is not centrally concerned with social outcomes, but rather how to manage specific technological transitions that affect the ways a given society satisfies needs and desires.
Social-Ecological Systems Framework	Incorporates Ostrom's insights on governance systems for achieving sustainable resource management, especially at the community level for well-defined common property resource systems (e.g. fisheries, forestry, irrigation).	Serves as a diagnostic tool that organises a long list of potentially interacting variables into core sub-systems that can be used as a transdisciplinary checklist for understanding outcomes in specific contexts.
Social Provisioning Perspective	Identifies unstable trends in capitalist societies. Rejects the mainstream economic vision of market failure due to non-market "externalities" because economic activity is always embedded within, and dependent upon, a non-market social and ecological context.	Recognises that uncertainty, history, power, and differential characteristics (e.g. class, gender, race) will affect the process of how and why goods and services are produced (and for whom), and the outcomes this process delivers.
Systems of Provision	Can identify how resource use is impacted by a very specific system of provision in each place and time. The implications are that there is no "optimal" System of Provision, and sustainability solutions require close attention to material culture in each case.	Is useful for investigating the material culture and provision of "need satisfiers" through political economy analysis of the chain of activity connecting production to consumption of specific goods and services.
Theories of Practice	Has been applied to demonstrate how societies get "locked in" to high resource use through the coevolution of high-energy technologies, institutions, and meanings.	Well-being and health outcomes are not a central concern, although they have been seen as emergent properties of engagement in specific sets of social practices.

5.1 Relevance to Sustainable Resource Use

Most of the theories accommodate environmental limits as exogenous factors that can affect the supply of resources available to a given society, rather than as internal variables with sustainability thresholds. As a result, these theories do not provide much guidance on feedback effects that might occur as a result of decisions to bring resource use back within planetary boundaries. That being said, exogenous sustainability limits are not necessarily a problem for the purpose of understanding provisioning systems if they are integrated within a broader framework that defines such limits (i.e. the SJS framework).

The way in which capitalism drives social–political processes is a particularly important topic that is covered well by the heterodox economics theories, but little attention has been given to the

sustainability of biophysical resource use in these theories. Conversely, many authors in the field of ecological economics focus on biophysical drivers and consumption growth without confronting the root causes of unsustainability and injustice, namely the logic of capitalist accumulation and the role of unequal power relations (Pirgmaier and Steinberger, 2019). There is some literature, especially in the fields of political ecology and degrowth, that marries these concepts and explores implications for technology, democracy, and political economy, but many questions remain underexplored (see Kallis et al., 2018 for a recent review).

Most of the theories are good at providing historical accounts to understand how unsustainable levels of resource use have become locked in, but they are generally much weaker at describing how to overcome these undesirable practices and processes. In terms of forward-looking approaches, quantitative complex systems modelling, such as System Dynamics, offers one of the few options to explore the feedbacks and trade-offs around how to achieve given social outcomes within planetary boundaries. Such models have recently been applied to formally demonstrate the feasibility of scenarios that achieve social targets within environmental limits for regions (Cooper and Dearing, 2019), nations (D'Alessandro et al., 2020; Victor, 2019), and for the world as a whole (Randers et al., 2018).

However, a downside of these formal models is that they are time- and resource-intensive, subject to many simplifying assumptions made by the modeller(s), and tend to overlook less tangible aspects of social change (Turnheim et al., 2015). Another complication arises if model results are understood as an "early warning signal" because people may change their behaviour in response, though not necessarily in predictable ways (Bentley et al., 2014).

5.2 Relevance to Sufficient Social Outcomes

Overall, we find that most of the theories are not concerned with the achievement of sufficient social outcomes as an end goal, but rather emphasise how processes may cause needs and wants to vary under different circumstances (Table 1). The Social–Ecological Systems Framework is notable for not being explicitly concerned with well-being at all, as long as resources are being used sustainably. Systems of Provision, by comparison, is well-suited to study the challenges and opportunities of satisfying culturally-specific needs in a particular time and context, while Complex Adaptive Systems provides tools to take these insights and explore different (stylised) contexts over time.

The Systems of Provision approach allows researchers to understand provisioning in terms of what is being produced, which is helpful for analysts studying different need satisfiers, such as food or education. A growing number of studies emphasise how the processes of privatisation and fiscal austerity have generally eroded the context-specific provision of social outcomes in recent years, such as life satisfaction (Boffo et al., 2017), housing (Robertson, 2017), and water (Bayliss, 2014). If social thresholds are defined (i.e. by the SJS framework), then forward-looking complex systems tools, such as System Dynamics, can model scenarios that explore the effects of such processes on the achievement of social goals over time.

6. A General Approach for Analysing Provisioning Systems

We find that there is no single theory that fits our purpose, which is to understand the ways in which provisioning systems generate social outcomes at more (or less) sustainable levels of resource use. In this section, we draw upon our analysis of the theories to identify broad features of provisioning systems, namely their elements (Section 6.1), their relationships (Section 6.2), and how well they achieve their overall purpose (Section 6.3). The elements and relationships that we identify are drawn from the six theories. Some are key parts of multiple theories, while others are under-

represented across the theories (see Supplementary Information Table S2 for a map). Our selection is ultimately informed by their relevance to the SJS framework. Finally, we integrate these insights into a revised version of O'Neill et al.'s (2018) analytic framework (Section 6.4), and discuss its application to analysing energy provisioning systems (Section 6.5).

6.1 Provisioning Elements

We have defined a provisioning system as "a set of related elements that work together in the transformation of resources to satisfy a foreseen human need", such as adequate nutrition, education, and social support (see Section 2.2). Based on our analysis of the six theories, we suggest that provisioning systems vary across societies due to differences in two broad groups of related elements, namely institutions and technologies.

6.1.1 Institutions

Institutions are elements that structure human interactions through social rules which are established and prevalent, but also adaptable (Hodgson, 2006). Several fields, notably social policy theory and economics, distinguish core institutional elements such as *households, markets, the commons, and the state*. Raworth (2017a), in fact, singles out these four elements as important "realms of provisioning" (p. 78). Each of these core elements can be seen as a sub-system with its own set of related elements and purpose that contributes to production and distribution in the provisioning process, but in different ways.

For example, households provide care for their own members, and care is a key element in the Social Provisioning Perspective, especially in relation to the sustaining role of unpaid care to the labour process. The commons provide co-created goods and services for the communities involved, which is the motivation of the Social–Ecological Systems Framework (e.g. how communities self-organise to use common property resources sustainably). The state provides public goods and also formal rules for the population, including rules that govern how markets provide private goods for people able and willing to pay.

The provisioning of goods and services differs across each of these institutions in terms of underlying values and principles, how provisioning is financed and regulated (Powell, 2019), and which institutions dominate provisioning (Esping-Andersen, 1999, ch. 5). These differences have resource use implications because they allow some societies to take environmental limits into account more than others (e.g. depending on the type and extent of state regulation or collective self-regulation of provisioning).

6.1.2 Technologies

Technologies refer to the collection of devices and engineering processes available to a society (Arthur, 2011). Here, we identify two core technological elements, namely techniques and material stocks. Techniques bring together the tools and competences available to a society to transform materials, energy, and information from one state to another. Material stocks represent the physical infrastructure available to a society (such as buildings, transport, and energy infrastructure), which shape the flow of resources used to provide essential services (Haberl et al., 2019; Pauliuk and Müller, 2014). This "stock–flow–service" distinction is underrepresented across the theories that we analysed (see Table S2), and often missing from institutional explanations of provisioning.

Technologies influence the resource efficiency of need satisfaction through differences in the production techniques used along international supply chains, and the levels of resources locked into maintaining the material stocks that connect them (Foxon, 2011). For example, the energy use and carbon emissions associated with the satisfaction of the needs for shelter and mobility depend

in part on the type of housing, and the infrastructure that connects people to where they live (Ivanova et al., 2018).

6.2 Relationships

Changes to the relationships between elements can be more effective than changes to the elements themselves, because they can shift the entire structure of a system (i.e. changing the "rules of the game"; Meadows, 2010). All of the theories aim to understand how system behaviour emerges from interconnected relationships between elements. The theories highlight two general types of relationships that define the complex and context-specific structure of provisioning systems, namely feedbacks and power relations.

6.2.1 Feedbacks

It is notoriously difficult to understand how the interplay between reinforcing feedbacks, which amplify changes, and balancing feedbacks, which buffer changes, affects system behaviour. The number of possible feedbacks within a provisioning system can be overwhelming, and emergence reminds us that these may all change through time (Verburg et al., 2016). For example, the build-up of material stocks can be seen as the result of past decisions taken within provisioning institutions (i.e. households, markets, the commons, and the state), but material stocks also shape the production and distribution choices available in the present and future.

In terms of analysing feedbacks, the concept of general resilience provides insight into how configurations of elements and their relationships can be more likely to foster or erode the capacity of a system to adapt or transform in response to external pressures (for instance the climate emergency). Resilience is most developed in Complex Adaptive Systems, which explicitly recognises the deeply uncertain yet fundamental role of feedbacks for understanding tipping points and regime shifts, but it is also similar to the notion of "lock-in", which is more common in the Multilevel Perspective and Theories of Practice. Resilience is often seen to have a positive connotation, while lock-in tends to have a negative connotation. However, the basic concept is neither good nor bad; its desirability depends on the regime at hand, and the challenge that regime is facing. For understanding how to influence the resilience of provisioning systems through their interconnected elements, several studies have identified a relatively small set of conditions, such as levels of diversity, connectivity, and the strength of feedbacks (e.g. Biggs et al., 2012; Carpenter et al., 2012; Preiser et al., 2018).

6.2.2 Power

Most of the theories we assessed mention the importance of *power relations*, which shape the interactions and outcomes that do and do not occur across the different elements of a given provisioning system. However, with the exception of feminist and Marxist influences in the Social Provisioning Perspective and Systems of Provision, the other theories provide few tools to investigate the sources and use of power explicitly. Socialist feminist approaches see power as a relation between individuals and groups based on a specific structure of exploitation, namely that some people have power and accumulate wealth/influence because they exploit the labour and powerlessness of others (Young, 2011).

Although the notion of power may be contested, we agree with Fuchs et al.'s (2016) claim that "an explicit examination of power can make visible the otherwise invisible workings of power in (…) consumption practices. Once these workings are revealed, they can be scrutinised, assessed and judged on ethical or other grounds, and challenged and changed, or embraced and expanded" (p. 301). For example, recent research on the large-scale proliferation and influence of climate

misinformation campaigns has revealed a coordinated network of think-tanks, advocacy groups, and shell corporations enabled by philanthropic and industry funding (Farrell et al., 2019).

6.3 Achievement of Purpose

According to Meadows (2010), redefining the purpose of a system is one of the most effective ways to create transformative change, and also one of the hardest. Based on our definition, the purpose of a provisioning system is to satisfy a foreseen human need. In the context of the SJS framework, we draw on our analysis to identify two obstacles to the satisfaction of needs at a sustainable level of resource use, namely the low resource efficiency of need satisfaction in high-consuming societies, and conflicting sub-purposes among provisioning system elements.

6.3.1 Resource Efficiency of Need Satisfaction

The reference to *foreseen* human needs in our definition of provisioning systems is meant to convey the view that levels of resource use and need satisfaction are not externally fixed. The manner in which culturally specific need satisfiers are fulfilled is both an outcome—and a determinant—of the set of provisioning institutions and technologies involved. This view is consistent with O'Neill et al.'s (2018) analytic framework, which shows bi-directional links between natural resources, provisioning systems, and need satisfiers (see Figure 2).

While human needs are seen to be universal (Doyal and Gough, 1991), the resource efficiency of meeting human needs may be improved by adopting need satisfiers that require lower resource inputs (e.g. replacing private vehicles with mass transit). Importantly, we do not use the term "resource efficiency" in the economic sense, as resource use per unit of Gross Domestic Product (GDP). There are well-known problems with pursuing gains in this type of efficiency, such as the "rebound effect", in which efficiency improvements can lead to higher resource use as costs fall (Polimeni et al., 2008).

Instead, we use the term efficiency in the sense that it is used in the environmental efficiency of well-being (EWEB) literature (e.g. Dietz et al., 2009; Knight and Rosa, 2011). In this literature, efficiency means achieving a high level of human well-being at a low level of resource use. The SJS framework introduces the additional constraint that the level of resource use must be high enough to satisfy basic needs, without transgressing planetary boundaries.

This approach is informed by the theories we analysed, notably Systems of Provision, which provides tools to analyse differences in material culture, i.e. how specific cultures emerge from the interplay between people and objects (Bayliss et al., 2017). The need to understand this interplay in specific contexts is gaining traction in the literature, with greater emphasis being placed on changes to lifestyles and social norms, as a means to achieve environmental targets. For example, the upcoming sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) will include a chapter on demand, services, and social aspects of mitigation for the first time (Creutzig et al., 2018).

6.3.2 Conflicting Purposes: Provisioning and Appropriating

Complex systems are usually structured hierarchically, as sub-systems within a larger system. Importantly, the purpose of a sub-system can come into conflict with the purpose of the larger system (Meadows, 2009). This situation may also occur with provisioning systems and their sub-elements.

One system, in particular, deserves special attention when it comes to understanding obstacles to the satisfaction of needs at a sustainable level of resource use: systems that extract economic rents. Following Stratford (2020), we define rent as an economic reward that arises from the recipient's control of strategic assets which exceeds the proportionate compensation of their labour.

To better understand the structure and process of rent extraction within provisioning systems, we introduce the concept of "appropriating systems", which we define as a set of related elements that work together in the transformation of resources to extract rent. Our view of appropriating systems is rooted in conflict-based theories of (under)development that emphasise how powerful actors accumulate disproportionate shares of resources and maintain social stability through coercion and hegemonic influence (D'Alisa and Kallis, 2020; Hickel, 2018b; Pirgmaier and Steinberger, 2019). In conflict-based theories, there is an important role for strategic civil resistance movements that confront powerful institutions based on moral and ethical principles that run counter to the injustices of the status quo (Engler and Engler, 2017). A prominent current example is Extinction Rebellion, a nonviolent civil disobedience movement to avert climate and ecological breakdown (Extinction Rebellion, 2019).

Appropriating sub-systems are similar to provisioning systems in the sense that the levels of resource use associated with rent extraction may differ across societies for the same broad reasons discussed in Section 6.1, namely due to institutions and technologies. However, a crucial difference is that provisioning systems satisfy human needs, which are universal for all people, whereas appropriating systems extract rents to satisfy the *wants* of a small section of society (e.g. a wealthy elite), at the expense of efficient social provisioning. The concept of appropriating systems reminds us to explicitly examine how institutions and technologies may be rigged in favour of particular groups.

6.4 Revised Analytic Framework

In this section, we reconsider the mediating role of provisioning systems in O'Neill et al.'s (2018) analytic framework (Figure 2), which conceptualises the links between resource use and social outcomes. Drawing on the previous sub-sections, there are three main changes that we propose to the framework (Figure 4).

First, we argue that each need satisfier can be mapped one-to-one onto a corresponding provisioning system, with elements of different provisioning systems being shared (see Section 2.2). The relationships between resource use and social outcomes within a given society are thus mediated by a set of overlapping provisioning systems that each satisfy a foreseen human need. In contrast, the way that provisioning systems map onto need satisfiers is not addressed in O'Neill et al.'s analytic framework.

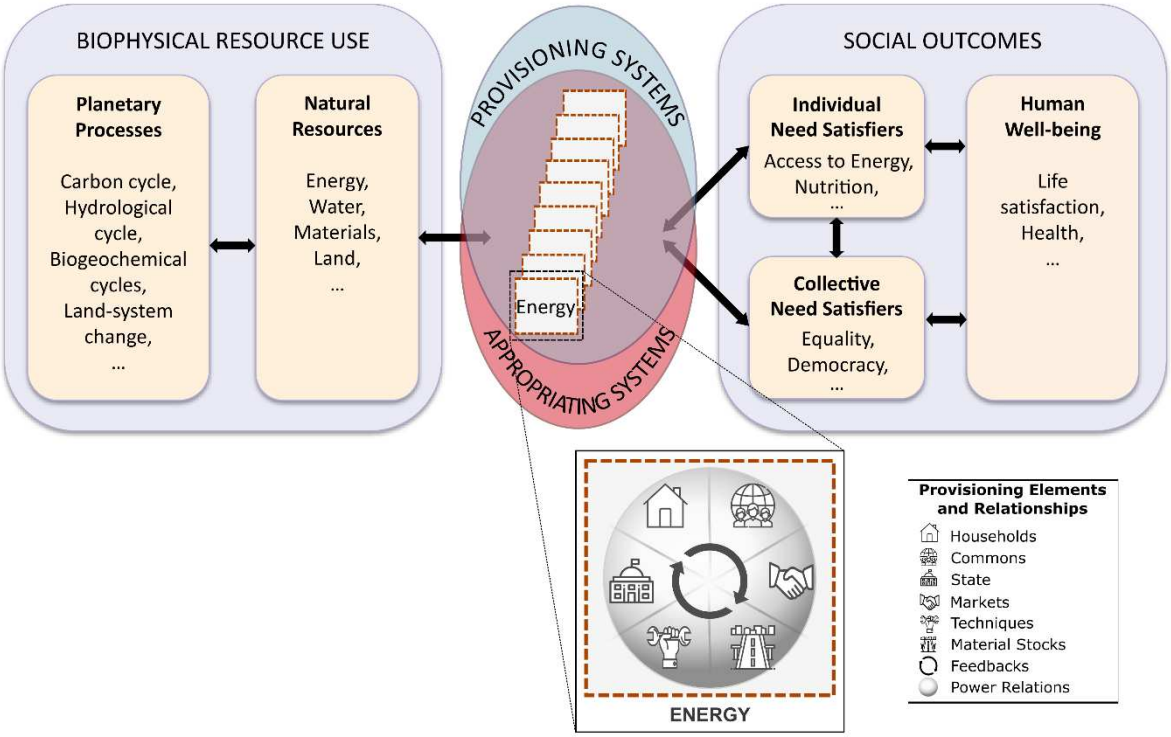

Figure 4. Revised analytic framework showing the links between planetary processes and human well-being. The relationships between resource use and need satisfiers are mediated by a set of provisioning systems that each satisfy a foreseen human need. Within each provisioning system there are appropriating sub-systems that may interfere with the satisfaction of human needs. Each provisioning system depends upon an open exchange of materials, energy, and information with its surroundings (dashed line), and is formed by an interconnected set of institutional and technological elements that generate feedbacks and reproduce power relations (inset).

Second, any society must organise itself in some way to produce the material conditions required to meet individual and collective needs, which leads people to enter into relations of production with one another. These relations establish a hegemonic social order that can be more or less equal (Fine and Saad-Filho, 2010). While there will likely always be some degree of rent extraction as societies work to meet their needs, the strength and legitimacy of appropriating systems deserve special attention because they maintain powerful actors who are entrenched in the status quo. We believe that appropriating systems, which are not included in O'Neill et al.'s analytic framework, must be better understood to overcome obstacles to transformative change.

Third, we identify six interconnected elements that all contribute in different ways to production and distribution in the provisioning process. These include two technological elements (techniques and material stocks) and four institutional elements (households, markets, the commons, and the state) (Figure 4, inset). These elements are interconnected with feedbacks and power relations running both between and within them. In contrast, O'Neill et al.'s analytic framework distinguishes between physical and social provisioning systems, but this distinction is difficult to define in practice because most elements arguably contain a mix of both aspects.

6.5 Applications

Overall, we believe this revised framework allows us to more systematically analyse and explore how social thresholds can be met within planetary boundaries. To apply the framework, the first step is to measure resource use and social outcomes relative to the sustainability and sufficiency conditions of the SJS framework. Once a given society has an idea of where it stands relative to the safe and

just space, the next step is to map provisioning systems onto individual need satisfiers in order to identify opportunities for, and barriers to, achieving the specific changes needed.

For example, the overall purpose of energy provisioning systems is arguably to provide "affordable, reliable, sustainable, and modern energy for all", i.e. Sustainable Development Goal 7 (UNGA, 2015). However, the global fossil fuel share of total final energy consumption is over 80%, and more than 800 million people still have no access to electricity (UN Economic and Social Council, 2019). Here, we identify some initial research questions that we believe are relevant to carry out this mapping process for a given society's energy provisioning systems:

- Institutions: What are the different roles of households, the commons, markets, and the state in the energy provisioning process? Which institutions dominate provisioning?
- Technologies: What are the existing techniques and renewable/non-renewable infrastructure in energy provisioning?
- Feedbacks: How can we characterise the path-dependent relations linking institutions and technologies to understand the undesirable resilience of fossil-based energy?
- Power Relations: What are the different sources of political and corporate power in energy provisioning systems, and how are they wielded?
- Conflicting Purposes: How do existing need satisfiers and/or the sub-systems of different institutional elements conflict with the overall purpose of providing "affordable, reliable, sustainable, and modern energy for all"?

After more than thirty years of climate delay, there is an urgent need to understand how the global fossil-fuel based energy system is sustained, and what might facilitate its transformation. Recent research has begun mapping the feedbacks and complexity in transitions to low-carbon energy systems (e.g. Bale et al., 2015; Foxon, 2011), and the mobilisation of funding by powerful industries and individuals in climate misinformation campaigns (e.g. Farrell et al., 2019; Supran and Oreskes, 2017). However, a systematic analysis that considers both feedbacks and power relations could help identify opportunities and barriers to effectively transform energy provisioning systems, which have proven elusive to date.

7. Conclusion

This article explores the emerging concept of provisioning systems. It proposes an analytic framework to (a) help understand why levels of resource use and social outcomes vary across different societies, and (b) help identify obstacles to improving the resource efficiency of human well-being in the context of planetary boundaries. Within it, we make four important contributions.

First, we define a provisioning system as a set of related elements that work together in the transformation of resources to satisfy a foreseen human need. This definition establishes the system boundary of a provisioning system, and the elements, relationships, and purpose that comprise it. Each need satisfier can be mapped one-to-one onto a corresponding provisioning system, while elements of different provisioning systems may be shared.

Second, we analyse six established theories against five criteria, with the aim of assessing whether they are useful for understanding links between resource use and social outcomes in the context of the SJS framework. The SJS framework provides a valuable tool for measuring social and environmental sustainability, but it tells us little on its own about how to achieve either of these goals. Our hypothesis was that existing theories could contribute to a better understanding of the links among variables within the SJS framework, where these links are conceptualised in terms of provisioning systems.

The theories that we analysed all seek to understand complex behaviour through a focus on interconnected relationships. They include Complex Adaptive Systems, the Multilevel Perspective, the Social Provisioning Perspective, the Social–Ecological Systems Framework, the Systems of Provision approach, and Theories of Practice. Three of the analysis criteria were drawn from systems thinking (i.e. scope, core elements and relationships, and vision of how change happens), while the other two criteria were taken directly from the SJS framework (i.e. sustainable resource use and sufficient social outcomes).

We find that there are components of existing theories that are helpful, but also gaps, in part due to the explicit focus on limits (both biophysical and social) within the SJS framework, and the wide scope that the framework encompasses (from planetary processes through to human well-being). No single theory provides a complete understanding of the complex links between resource use and social outcomes. Sustainability targets are generally viewed as exogenous constraints across the various approaches, while most of the theories fail to prioritise human well-being and needs explicitly. The majority of the theories provide compelling historical accounts to explain current system behaviour, but none of them helps to fully understand the ways in which provisioning systems mediate levels of resource use and need satisfaction.

Third, based on our assessment of the theories, we identify six important elements of provisioning systems that may be analysed and compared (households, markets, the commons, the state, techniques, and material stocks), and two types of relationships that are also important to explore (feedbacks and power relations). A better understanding of these aspects may provide opportunities to change both provisioning systems and need satisfiers so that human needs may be achieved in a less resource-intensive way.

Finally, we propose the concept of appropriating systems as a component of provisioning systems. We see the relationships between resource use and social outcomes as mediated by the interplay between provisioning and appropriating systems. These systems have overlapping purposes that may conflict with one another (satisfying human needs on the one hand, and extracting economic rents on the other). The concept of appropriating systems provides an additional tool to analyse—and ultimately confront—obstacles to transformative change.

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