SOCIAL SCIENCE AND SUSTAINABILITY

Engage key social concepts for sustainability

Social indicators, both mature and emerging, are underused

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With humans altering climate processes, biogeochemical cycles, and ecosystem functions (*1*), governments and societies confront the challenge of shaping a sustainable future for people and nature. Policies and practices to address these challenges must draw on social sciences, along with natural sciences and engineering (*2*). Although various social science approaches can enable and assess progress toward sustainability, debate about such concrete engagement is outpacing actual use. To catalyze uptake, we identify seven key social concepts that are largely absent from many efforts to pursue sustainability goals. We present existing and emerging well-tested indicators and propose priority areas for conceptual and methodological development.

POLICY

Indicators represent a particularly powerful tool. They are scalable across geographic areas and, when designed well, reduce complex phenomena to simple measures (*3*). Social indicators can be used to ensure accountability or track progress toward normative goals, for example, increasing well-being (*3*, *4*). Further, they can evaluate local conditions to direct decision-making for more desirable futures, for example, by identifying if local values are conducive to collective management approaches. Indicators can thus describe what exists, and in doing so, they define what is important. Conversely, that which is not measured can disappear from public debate and political consciousness (*3*). Bias toward easily quantifiable concepts, coupled with the tendency for indicators to direct change, can hinder progress, particularly where biases ignore key determinants of human equity and action (*5*). Consequently, suitable indicators are required for key social phenomena fundamental to a sustainable future.

PROMISING SOCIAL INDICATORS. Human well-being is dependent on healthy ecosystems, yet short-term pursuit of well-being may negatively affect those same ecosystems (*6*). Tracking only economic growth has been detrimental to social and environmental progress (*4*), which demonstrates the need for broader understanding and assessment of human well-being. The recent surge of interest in measuring well-being from local to national scales has tended toward consensus around what to measure and how (*4*, *7*). Human well-being remains variously defined but can be thought of as a state of being with others, where human needs are met, when individuals can act meaningfully to pursue self-defined goals, and when they can enjoy a satisfactory quality of life (*4*, *8*). Well-being is thus multidimensional (i.e., more than gross domestic product or happiness) and consists of both objective and subjective elements (i.e., it reflects what people have or have achieved and how they feel about this). Although well-being manifests differently across contexts, three components appear universal: material well-being, quality of

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life, and relational well-being (*7*). These established, multidimensional elements have well-tested indicators (see the table).

Material well-being, quality of life, and relational well-being can in part be understood from people's values. Values reflect the importance something holds for us and, in doing so, guide human thinking, feeling, and behavior to frame the pursuit of well-being. Social psychologists in particular have developed systematic approaches to assess values. Values in this sense are transsituational goals that vary in importance and serve as guiding principles in people's lives, such as conformity or compassion (*8*). Broad agreement has emerged that a limited number of values exist, that they relate to each other in a consistent manner, and that specific values are similar to one another, whereas others conflict. Analogous to the agreed upon constituents of well-being, all identified values are considered present, in varying degrees of importance, in all human societies (*8*). Academics and international agencies have measured a common set of values, across nearly 100 countries, that represent more than 85% of the world's population (*8*) (see the table).

The success of sustainability polices will be influenced by agency: the ability to act (and achieve) on the basis of what one values and has reason to value (*9*). People often strive to adapt to their social systems (e.g., laws and policies) and their natural environments (e.g., resource availability) as they pursue greater well-being for themselves and their families. Where people have agency, they may reject policies that impinge on their values or their ability to improve well-being. Where people lack agency, they may be unable to take advantage of the potential for desirable change or may be coerced into undesirable situations. Trajectories to desirable futures can falter because people have, or lack, agency, even when values have been used to inform policy. Measures for agency are less developed than those for human well-being or values, but progress has been made (*10*). Indicators often measure assets (e.g., education); control over specific domains (e.g., household decision-making); or global proxies (e.g., the "ladder of power") (*10*) (see the table). There is mounting evidence that multidimensional process-based measures of agency are necessary to account for people's (i) direct control or effective power; (ii) ability to pursue and achieve goals; (iii) capacity to direct their pursuits toward what they value or have reason to value; and (iv), ability to improve their own, or others', well-being (*10*).

Inequality—the unequal distribution of costs, benefits, power, and access to resources—exacerbates both socialand environmental conditions; it undermines sustainability (*11*). Inequalities shape who has agency and who lacks it (*11*). Consequently, reduction of inequality is a central theme in the United Nation's Sustainable Development Goals. Indicators of inequality have not been specified, but, analytical lenses have been developed (see the table).

Social measures for sustainability

Promising indicators for measuring well-being, values, agency, and inequality

WELL-BEING

1. OECD's "how's life" framework (*7*). Quality of life: Eight elements (e.g., health status, subjective well-being). Material conditions: Three elements (e.g., income): Sustainability of well-being over time: Four capitals (e.g., human, economic, social, and natural).
2. Millennium Ecosystem Assessment 2003 from "voices of the poor" (*7*). Material well-being (e.g., enough food); bodily well-being (e.g., health); security (e.g., civil peace); freedom of choice and action; social well-being (including psychological well-being, self-respect and dignity, peace, harmony, and good relations).
3. Ten universal capabilities [e.g., Nussbaum 2001 (*7*)]. Life; bodily health; bodily integrity; senses, imagination, and thought; emotions; practical reason; affiliation; other species; play; control over one's environment (e.g., political and material).

VALUES

1. Human values [e.g., Schwartz *et al*., 2012 in (*8*)]. Two dimensions capturing self-enhancement to self-transcendence and openness-to-change to traditionalism that contain 10 value types.
2. World values survey [e.g., Inglehart and Welzel 2005 in (*8*)]. Two dimensions capturing traditionalism to secularism and survival to self-expression.
3. Cultural dimensions theory [e.g., Hofstede 2001 in (*8*)]. Six dimensions capturing individualism to collectivism; uncertainty avoidance; social hierarchy; masculinity to femininity; long-term orientation; indulgence to self-restraint.

AGENCY

1. Moving out of poverty's "ladder of power" [Narayan and Petesch 2007 in (*10*)]. Assesses one's power up a hypothetical ladder.
2. Agency and empowerment [Alsop and Heinsohn 2005 in (*10*)]. Reflects asset endowments (e.g., psychological, informational, organizational, material, social, financial, and human).
3. Demographic and health survey [Orc-Macro 2006 in (*10*)]. Determines control over six domains (own earnings, partners earnings, own health care, major household purchases, daily household purchases, visits to family).

INEQUALITY

1. Gini index [e.g., (*11*)]. Measures the extent to which the distribution of income deviates from perfectly equal.
2. Social mobility indices [e.g., (*11*)]. Measures the movement of individuals, families, households, across a social layer (e.g., changes in income levels, education levels).
3. Fractionalization indices: Measures the social heterogeneity and conflict in a group.

CONCEPTUAL AND METHODOLOGICAL NEEDS. Power, the ability to influence or control the beliefs or actions of others, is created by, and recreates, many inequalities, which include the ability to exercise agency (*12, 13*). Power at different scales can be exerted over others, through various means (e.g., knowledge or policies), or to achieve certain ends. Understanding and monitoring power that is exerted in both overt ways (e.g., state control) and diffuse ways (e.g., hegemonic ideas) is central to crafting a sustainable future. Work is needed to determine how elements of power, in the context of sustainability, can be measured and monitored through time. These efforts may draw from progress in related fields; for example, the Herfindahl-Hirschman index measures the extent to which market shares are concentrated within a few companies and could be adapted to measure the extent to which influence is concentrated within a few individuals, organizations, or states. Social network analyses can be used to measure the influence of a group, organization, or idea.

Existing measures of values may provide broad context for well-being but may lack the depth and breadth that an understanding of culture enables. Culture is a multifaceted concept that includes the shared language, knowledge, meanings, values, beliefs, norms, customs, and practices that are transmitted through social learning (*14*). Culture is expressed through social, political, and economic systems, as well as through symbols, artifacts, and landscapes, such as the British badger or suburban American lawn, that serve to reinforce beliefs or norms of behavior. Comprehensive indicators of culture are yet to be developed, but indicators exist for elements of culture, such as place attachment. A comparative cultural database, based on in-depth ethnographic work, exists for nearly 300 cultures, and it could inform a measurement-based indicator system (ehrafworldcultures.yale.edu).

Although inequality may persist, the extent to which this represents an injustice determines when conflict may arise and action is necessary. Thus, progress toward sustainability goals must be evaluated through the lens of justice, a normative principle centered on how people should be treated (*15*). Existing indicators assess distributional and procedural justice in workplaces, or environmental injustice in federal jurisdictions; however,

adequately addressing justice will require additional assessments of what is considered "fair," to and by whom, and programmatic steps regarding how justice can be achieved and maintained (*15*).

Progress has been made toward development of some indicators, and in many instances, relevant data and expertise exist within national and international, official and unofficial statistics bureaus (e.g., national censuses, representative surveys, and polling reports). Further work is needed to understand and communicate desirable directions of change. Reasonable consensus exists that it is desirable to increase well-being and agency and to reduce inequality, injustice, and imbalances of power. In contrast, although extreme values are detrimental to sustainability goals, there is no desirable direction of change for values or culture. Instead, these concepts facilitate understandings of how sustainability goals manifest and how policies can be crafted. Although critical gaps remain with concepts in need of indicator development, quantitative indicators are alone insufficient for understanding these concepts. Complementary, qualitative, and reflexive assessments will remain critical for development, implementation, and interpretation of robust measurement systems. ■

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SELF-ASSEMBLY

Colloidal crystal ordering in a liquid crystal

A nematic phase promotes the formation of dilute, low-symmetry colloidal crystals

By **Christophe Blanc**

Nanoparticles (NPs) can now be synthesized with a wide array of controlled sizes, shapes, and properties. However, turning them into nanomaterials often requires packing them into ordered assemblies to manifest specific electronic or optical properties for applications in nanoelectronics, optics, and metamaterials. Colloidal self-assembly (*1*) of NPs is relatively simple but is often restricted to high-symmetry crystals by the lack of specific directional bonds, especially for dilute NP solutions. To obtain lower symmetries that confer useful optical or electronic properties, long-range directional interactions must be imparted. On page 69 of this issue, Mundoor *et al.* (*2*) make clever use of an anisotropic host fluid, a liquid crystal, to promote the formation of a low-symmetry crystal in a dilute dispersion of nanorods.

In simple fluids, the absence of directional interactions between dispersed particles tends to favor the formation of only a few types of crystals. For example, concentration of hard spherical colloids mainly produces high-symmetry face-centered cubic or hexagonal close-packed lattices. Progress in colloidal engineering has partially lifted this limitation with the introduction of colloidal particles that can organize via directional interactions because of the specific control of their shape or of their surface patterns (*3*). Such "shape-anisotropic" or patchy colloids can promote preprogrammed structures when they are in close contact, but their interactions in dilute dispersions remain mostly isotropic.

Mundoor *et al.* show that the situation can be very different in a liquid crystalline matrix when the proper combination of interactions is present. They studied the dispersion and self-assembly of semiconductor nanorods in an aligned nematic liquid crystal. In thermotropic nematic phases, rodlike molecules develop a long-range orientational order caused by the spontaneous molecular alignment. The alignment occurs only over a given temperature range, and is a time average as the molecules can still move and fluctuate. Uniformly aligned domains are easily obtained at large scale in thin films formed over suitable substrates.

The spontaneous formation of colloidal crystals of the triclinic pinacoidal symmetry class (almost the lowest symmetry possible) was observed at very low concentrations (<<1%). In crystals of this class, none of the unit cell edges are equal, and none of the angles between the edges are equal, nor are they right angles. Repulsive electrostatic interactions between the NPs compete with attractive interactions mediated by the orientational elasticity of the liquid crystal (see the figure). The NPs have positive surface charges, and although they are elongated rods, the electrostatic interaction is effectively isotropic at large distances. However, each particle also gives rise to an elastic distortion of the matrix with a quadrupolar symmetry. This distortion creates the long-range and anisotropic elastic interactions between the NPs. The mesophase nature of the host is essential to the formation of the low-symmetry crystal because only the electrostatic repulsion remains if the liquid is heated into the isotropic phase, where the orientational ordering disappears.

> ***"The mesophase nature of the host is essential to the formation of the low-symmetry crystal..."***

The control of the organization of solid inclusions by means of mesophases already has a long history. For example, spontaneous alignment of nanorods by the nematic phase is well known and is caused by a restoring torque created by a preferred orientation of the host fluid molecules at the surface of the particles (a phenomenon called anchoring). This phenomenon was discussed theoretically as early as the 1970s

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