# Measuring China's Circular Economy

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ENVIRONMENT AND DEVELOPMENT

# Measuring China's Circular Economy

Unique environmental and economic challenges provide a laboratory for developing new indicator systems.

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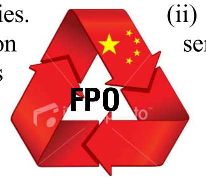
Facing significant natural resource consumption, environmental degradation, and resulting public frustration, China's new administration heightened attention on ecological modernization, green growth, and low carbon development, with a national circular economy (CE) strategy (*1*). The 2012 RIO+20 United Nations Conference on Sustainable Development emphasized the need to develop indicators of progress that decouple economic growth and environmental burden (*2*). We describe how China presents unique opportunities to develop new environmental indicator systems for measuring and managing CE, with particular focus on "emergy"-based indicators.

### CEs but Incomplete Indicators

A CE is an industrial system focused on closing the loop for material and energy flows and contributing to long-term sustainability (*3*). CE incorporates policies and strategies for more efficient energy, materials, and water consumption, while emitting minimal waste into the environment (*4*).

Germany and Japan were pioneers in CE-like policies. Germany's 1996 CE Law sought to reduce land use for waste disposal by focusing on solid waste avoidance and closed-loop recycling. In 2000, Japan's "Sound Material-Cycle Society" focused on solid waste management, land scarcity, and resource depletion because of concerns about shortages of landfill spaces and revitalizing local stagnating industries (*5*). CE in Japan includes "ecotowns" aimed at reducing landfill requirements (*6*) and product-specific recycling targets for waste categories to be reached through product stewardship schemes, levies, and voluntary regulatory initiatives for producers and consumers.

China's CE borrowed from Germany, Japan, the European Union (EU), and the United States by incorporating elements of take-back regulations, resource efficiency goals, reduction goals, and eco-industrial parks (*4*). But China's socioeconomic environment provides a context different from that of other nations, making it an ideal laboratory for new, expanded CE policies. For instance, Japan's effort focuses on redeveloping stagnating industries and Germany's, on waste-management goals, whereas China's CE is a broader systemic policy, more integrated at the national level to include development planning and requiring collaboration by numerous government agencies. These agencies are considering linking CE to China's low-carbon strategy (*4*).




China's CE has rapidly evolved. Its latest CE promotion law, adopted in 2009 (*4*), has gained recent political traction. National plans for safe urban municipal solid waste treatment (*7*), energy saving, and emissions reduction (*8*) are being implemented on the basis of CE principles. Government agencies are developing tax policies supporting resource recovery in industrial practices. Billions of dollars are being invested in CE-oriented pilot projects, from applications of clean production techniques in specific sectors to municipal and regional eco-industrial development.

Well-designed indicators are valuable for managing environmental development and providing guidelines to improve CE policies. Performance indicators for regions and industrial parks have been developed, based on well-known assessment methods: energy, material flow analysis (MFA), life-cycle analysis (LCA), $CO_2$ emissions, and economic returns (*4*). In spite of their usefulness, these indicators may not optimally fit CE assessment needs because they were not originally designed for the systemic, closed-loop, feedback features that characterize CE. Some disregard flow quality and characteristics and the complexity of interactions between the natural environment and socioeconomic systems (*9*).

Other indicators of eco-efficiency—carbon and ecological footprints, LCA, economic and energy valuation—mainly focus on individual parameters. Although useful at the local scale of specific processes or products, this specificity is unlikely to provide a complete picture for managing CE policy. Unidimensional indicators (i) focus on individual aspects of resource use and system metabolism—such as commercial energy demand, emissions, or economic value—often disregarding other parameters and driving forces; (ii) do not account for local ecosystem services or the value of existing natural capital, other than in monetary terms (e.g., *10, 11*), with incomplete assessments leading officials to pay less heed to protecting local ecosystems; (iii) call for policies optimizing an individual resource or flow, thus are less suitable to track diverse, nonlinear interactions between human society and the natural system in which economic processes are embedded; and (iv) lack the ability to address waste and emission management, reuse, and recycle strategies that characterize CE.

This suitability gap is more evident at the national and macroeconomic level. Although many indicators prove effective at the scale of specific products and processes, they are limited when considering the broader context and network of CE resource flows. The more complete role of natural systems as a source, sink, and regulator is missing.

### An Emergy Indicator System

Given CE's broad systemic aspects, monitoring can be enhanced through emergy-based indicators, a set of environmental accounting indices and ratios (*12*, *13*) capable of capturing both resource generation (upstream) and product (downstream) dimensions. Rooted in ecology, thermodynamics, and general systems theory, emergy is the sum of all available energy inputs directly or indirectly required by a process to generate a product (*12*). Emergy assigns value to nature's environmental effort and investment (e.g., solar, deep geothermal heat, and gravity) to make and support flows, materials, and services and to contribute to the economic system. Given that solar energy is the dominant energy input to Earth, emergy expresses all inputs and flows in solar-equivalent Joules (seJ), a critical feature that enables distinctions between qualities of resources that are not possible under other indicator systems based on user-side human preference values. For example, in energy analysis, a MJ from wood and a MJ from oil contribute the

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same amount to energy intensity indicators, yet wood and oil derive from different production patterns and generation times within natural cycles, requiring different amounts of solar energy [for photosynthesis (wood) and to convert biomass to fuel (oil)].

The ratio of emergy (seJ) required to make an amount of product (J) is defined as "transformity" (seJ/J) (*13*), a measure of production cost on the spatial and time scales of the biosphere. For example, production of one joule of electricity might require 2.5 J of natural gas, production of which might in turn require the equivalent of 170,000 J of sunlight. When adding the emergy of machinery, chemicals, labor, and environmental services, 1 J of electricity may require ~300,000 seJ. Flows of renewable, nonrenewable, local, and imported emergy resources (e.g., biomass, coal, or human labor) are ultimately used to calculate environmentally based, systemic performance indicators.

An emergy indicator system includes (i) intensity indicators that target convergence of resources per unit of product, of labor expended, of Gross Domestic Product (GDP) generated, of land developed, etc. and (ii) performance indicators, such as emergy yield ratio (emergy return on emergy investment), emergy loading ratio (a measure of carrying capacity), emergy density (emergy use per unit of time and area), emergy sustainability indicator (an aggregated measure of yield and environmental pressure), emergy investment ratio (emergy investment from outside for a local resource exploitation), and fraction of emergy that is renewable, among others, all of which support multiple performance aspects in resource use.

By accounting for quantity and quality of input flows, keeping track of interactions among system components across scales, and identifying environmental costs and savings of loop-closing strategies at all levels, emergy provides a systemic framework for assessing the performance and sustainability of CE, as well as specific CE implementation processes.

Emergy evaluation has been criticized for implicitly assuming that input resources can substitute for each other (*14*). But the "quality" feature embodied in the transformity concept (e.g., a joule of fuel is not the same, in environmental cost and functional terms, as a joule of sun or a joule of electricity) weakens this argument. Practical capabilities and capacities of emergy analysis have been demonstrated in several large-scale regional analyses [e.g., (*15*)].

Given CE's scale, use of an emergy approach does not exclude use of other indicators for their specific purposes, boundaries, and scales but, instead, provides a framework for integration of approaches (*16*). LCA can effectively measure downstream environmental burden, e.g., the impact of emissions in the production chain. Energy analysis accurately measures commercial energy cost of a product. MFA can measure mass degradation in a process. Emergy-inclusive CE indicators provide several characteristics that can be integrated with other evaluation methods:

(i) The emergy "supply-side" evaluation system focuses on nature's investment, on the work performed by the biosphere to generate resources and services, not only the economic value or the mass of resources supplied to the economic system (*17*). The latter often ignores contributions of ecosystems to economic development (*18*).

(ii) Perverse methods of allocating environmental burden may cause conflicts between regions (e.g., with burdens and benefits of coal extraction, energy consumption, and emissions unevenly distributed across coal-extracting and coal-consuming regions). A supply-side, emergy-based indicator approach helps track the entire "production cost." Broadened accounting of whole supply-chain burdens assigns environmental impacts more fairly and discourages inefficient and unnecessary resource depletion.

(iii) Emergy indicators reflect the space, time, and natural activities needed for resource production, which a CE cannot ignore.

(iv) A CE aims to mimic natural patterns, where resources are routinely recycled, reused, converted, upgraded, and stored for future use. In so doing, resources are not depleted, and waste does not accumulate. The emergy method quantifies both the direct and indirect environmental costs of waste management and untreated waste disposal as well as the advantage of recycling in closed loops (*19*).

### Toward a CE-Oriented Indicator System

Chinese researchers are studying emergy indicators for a large number of CE systems, but these studies are not well organized or unified. A national research committee on integrative environmental performance indicators should be established. Additional research on emergy indicators' integration with other tools is also needed. Planning and management mechanisms are needed to help determine how research on environmental performance indicators can proceed, with results shared among researchers and translated into practice. Databases and training opportunities at all levels are necessary. Dispersed international research efforts need convergence toward emergy as a useful policy-making instrument. In addition to the Chinese Academy of Sciences and Natural Science Foundation of China, the U.S. Environmental Protection Agency, EU, and the Italian National Agency for New Technologies, Energy and Sustainable Economic Development are pursuing projects to evaluate emergy's assessment capability. National governmental agencies (joint agencies in China, such as the Ministry of Environmental Protection and the Natural Science Foundation of China) or international groups, such as the United Nations and International Standards Organization, can provide avenues and repositories for CE-level emergy databases and resources to help emergy become a practical policy tool.

The use of more scientifically supportive and comprehensive environmental measures will aid the legitimacy of economic and environmental decisions concerning resource use and trade. Facing community protests and pressures from nongovernmental organizations related to environmental issues, the Chinese government must strike a difficult balance between scientific evidence and political expediency if their CE and national development effort is to be successful.

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