Three-Dimensional Product Circularity

Robert H.W. Boyer[1]*, *Ann-Charlotte Mellquist*[1], *Mats Williander*[1], *Sara Fallahi*[1], *Thomas Nyström*[1], *Marcus Linder*[1], *Peter Algurén*[1], *Emanuela Vanacore*[1], *Agnieszka D. Hunka*[1], *Emma Rex*[1], and *Katherine A. Whalen*[1].

*Corresponding Author (robert.boyer@ri.se)

[1.]RISE Research Institutes of Sweden AB. Gothenburg, Sweden.

Abstract

Understanding product circularity as "three-dimensional" could anchor the Circular Economy to common principles while affording its followers flexibility about how to measure it in their specific sectors, disciplines, and within their organization's means. Inspired by a heuristic developed for the urban planning profession to cope with the inherent conflicts of Sustainable Development, this article argues that measuring product-level circularity should consider ways to achieve 1) high material recirculation, 2) high utilization, and 3) high endurance in products and service offerings. Achieving all three dimensions ensures that material flowing through the economy is recovered from prior use phases, that it is used intensely, and that it retains its value in spite of exogenous changes. The article argues further that these three dimensions ought to be measured and reported separately rather than as a composite metric, and that certain applications will have opportunities to improve circularity through certain dimensions better than others. The article also explains how researchers at RISE (Research Institutes of Sweden AB) are working with industry and government partners to measure the three dimensions, and how diverse actors interested in the Circular Economy can use the three-dimensional to take the first steps in their transition to circularity.

Introduction: Too many metrics?

The Circular Economy faces a dilemma. An organization interested in reporting and improving the circularity of its product or service can choose from a growing array of circularity assessment tools. Some organizations may even feel compelled to develop their own. The challenge, of course, is that the concept of circularity may lose its power to stimulate societal-scale change if firms, public agencies, and other organizations choose to define and measure circularity in the manner that is most convenient to themselves, and inconsistent with/contradictory to everyone else.

In some respects, such diversity is a sign that circularity has reached its adolescence. Drawing from philosopher W.B. Gallie (1956), Korhonen et al. (2018) argue that the Circular Economy is an "essentially contested concept" characterized by various and conflicting views about its meaning among a group of adherents that agree fundamentally about its appropriate application. Similarly, Blomsma and Brennan (2017) frame the Circular Economy as an umbrella concept that ''…create[s] a relation between pre-existing concepts that were previously unrelated, or not related in the manner the umbrella concept proposes, by focusing attention on a particular shared quality or characteristic of the concepts it encompasses'' (p. 604). Other authors have commented that circularity's many different definitions risk leading practitioners to conflicting conclusions about the same concept (Kirchherr et al., 2017; Moraga et al., 2019; Saidani et al., 2019).

Scholars and firms interested in advancing the Circular Economy may feel torn between two uncomfortable options: either A) continue to measure circularity in parochial ways that may not may contradict other formulations of circularity or B) accept a generalized definition of circularity that fails to account for diverse actors' particular needs and capabilities.

We argue for a third, more pragmatic approach informed by similar struggles with the concept of sustainability.

Some help from urban planners: The Planner's Triangle

Sustainable Development faced a similar dilemma in the latter decades of the twentieth century. After emerging first from different applications in agriculture and then appearing in several UN declarations, the sustainability label began to diffuse to national policies, cities, industries, academic programs, and individual products (Kidd, 1992). Keen observers began to voice concern that the concept had unraveled into meaninglessness: *if sustainability was everything, then maybe it was nothing*.

In 1996, scholar Scott Campbell helped settle the cacophony for the urban planning profession by publishing a now classic article describing Sustainable Development as a set of conflicts between three legitimate priorities of urban planning (Campbell, 1996). Achieving Sustainable Development, claimed Campbell, involved continuously resolving the conflicts between 1) environmental protection, 2) economic growth, and 3) social justice. Protecting the environment, for example, might involve imposing clean air standards that (temporarily) limit industrial profits; Growing the economy by building transportation infrastructure, for example, might spark a social equity dilemma by harming some neighborhoods while benefiting others; Achieving social equity by stimulating an increase in the supply of affordable housing might harm the local environment by spurring automobile traffic and paving over green spaces. And so on.

While many are likely familiar with sustainability as a three-pillared concept, it is important to note that Campbell's triangle was not prescribing that planners pay attention to all three priorities, but rather *describing* how most planners necessarily pay attention to all three. By encouraging urban planners to focus on resolving conflicts between the three priorities, Campbell reframed Sustainable Development as an ongoing process of problem solving instead of an allusive utopian destination with a single authoritative definition. While the "planners' triangle" did not completely clear the haze, and colleagues continued to add sustainability dimensions in attempts to broaden the concept (e.g. Godschalk 2004), the heuristic was nevertheless useful to urban planners struggling to make sense of a stylish but dangerously fuzzy concept.

The many meanings of circularity

The concept of circularity and the Circular Economy are experiencing a swell of excitement similar to sustainability's coming-of-age in the mid-1990s. While the two concepts share their roots in environmental movements of the 1960s and 70s, scientific and popular web searches for the term "circular economy" began to accelerate at the end of the first decade of the 2000s (Tóth, 2019) and the first academic article on indicators for circularity appears to have followed ten years later (Saidani et al., 2019).

Recent years have witnessed a small explosion of indicators, metrics, assessment tools, and checklists for circularity. This is due, in part, to the concept's application at multiple levels and by diverse sectors. There are now dozens of ways to verify the extent to which international organizations, nations, cities, businesses, and individual products are more or less "circular."

Michael Saidani and colleagues recently identified 55 different circular economy indicators used around the world, including 20 developed to measure the circularity of individual products (Saidani et al., 2019). Roos Lindgreen et al. (2020) offer an even more recent assessment, identifying 74 approaches to measuring circularity at the micro level. Most identified approaches are proposed by European authors, with a swell of newly proposed assessment methodologies in the year 2018. Their diversity is impressive. Some consider multiple recirculation pathways while others focus on only one (often recycling). Some offer insight on the lifecycle environmental consequences of a product while others focus strictly on the material composition of a product. Some metrics (30 percent) are designed for particular industries while others (69 percent) can apply in multiple sectors. Applying some metrics requires very specific data inputs (yielding relatively precise outputs) while others need only a rough judgement call (yielding rather imprecise outputs).

This proliferation of metrics ought to be welcomed with caution.

On one hand, organizations interested in the Circular Economy ought to have access to assessment tools that fit their particular challenges and their particular technical capacities. An architect assessing the circularity of a building, for example, might benefit from a circularity metric designed specifically for building materials (Verberne, 2016), but shouldn't bother using a tool designed for the Chinese iron and steel industry (e.g. Zhou, Chen, and Xiao 2013), or Chinese chemical companies (e.g. Li and Su 2012). A startup company just discovering the circular economy might not have the resources to correctly apply a multidimensional metric with complex data inputs (e.g. Ellen MacArthur Foundation and Granta Design 2015), but might find an exploratory metric (e.g. Evans and Bocken 2013) useful and practical. A firm interested in stimulating reuse and repair through a service-based business model is not best served by applying a metric focused exclusively on material recirculation (e.g. Linder, Sarasini, and van Loon 2017).

On the other hand, it is important that metrics for the Circular Economy share a conceptual reference point so that their application can encourage changes in society that contribute to similar goals, or at least avoid major contradictions. How might a company, a government agency, or a non-profit organization identify the appropriate tool for assessing their progress on circularity without distorting the meaning of circularity? How might a service-oriented business that doesn't engage in the manufacturing of goods measure the circularity of their offer? How might a city assess the circularity of a proposed building design without knowing precisely what types of materials will be included or precisely how its future inhabitants will use the space? How might a firm decide between components made of reused or recycled material (a seemingly circular option), and very durable, flexible, and adaptable design (also a circular option)?

The Three Dimensions: Recirculation, Utilization, Endurance

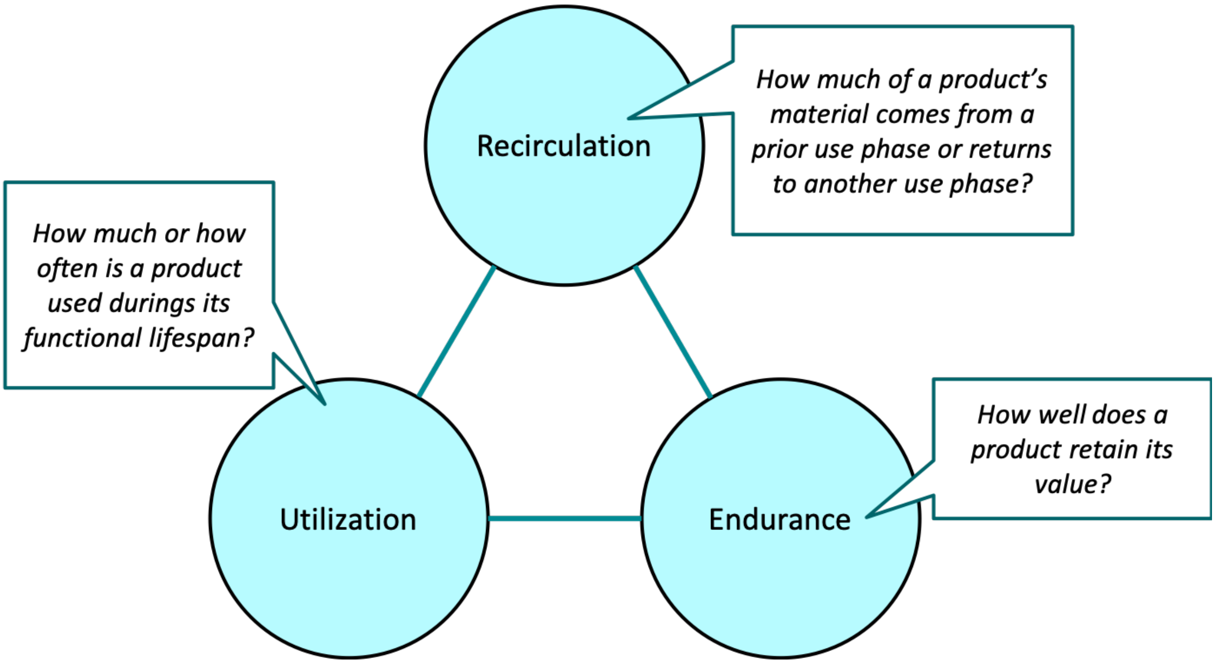
It is perhaps helpful to think of product circularity in three dimensions, similar to Campbell's triangle. We suggest the following three:

1) **material recirculation:** products shall be composed entirely of material recovered from some prior use (e.g. reused, remanufactured or recycled) rather than composed of "virgin" material;
2) **utilization:** products shall be used frequently rather than sitting idly (e.g. in storage); and
3) **endurance;** products shall retain their value over time, rather than becoming physically degraded or socially irrelevant (e.g. physically, technically, aesthetically, or socially obsolete).

In short, a product should be made of materials that have been used before. Once created, it should be used as often as possible, while remaining valuable as long as possible. It is naïve to believe that all products can maximize all three dimensions. Like Campbell's allusive "sustainable development", there is no single, authoritative destination. Nevertheless, attempting to maximize all three of these dimensions ought to reduce material throughput in the economy by keeping the material currently in use, in perpetual use.

It is perhaps easiest to understand the importance of each dimension by imagining a product that fulfills two dimensions, but not the third.

- A product made entirely of recycled content (high material recirculation) that is used intensely (high utilization) might break down relatively quickly (low endurance);
- A product used intensely (high utilization) without breaking down (high endurance) might demand stronger, newer materials (lower material recirculation); and
- A product with high recycled content and high endurance might as well have *never been produced* if it sits in storage without being used (low utilization).



Clashing priorities in the linear economy

Whereas Campbell's planner's triangle encourages urban planners to find resolutions to conflicts between economic growth, social justice, and environmental protection, so can the *three dimensions* of circularity encourage a transition away from traditional linear business models that often force clashes among the *three dimensions* of circularity. In the traditional "linear" economy, where **producers** and **consumers** benefit from the mass production of cheap goods and ownership of a good is typically transferred completely from one party to another, the three dimensions are in a constant state of conflict. Endurance and recirculation are in conflict because products built to endure for eternity might require more and/or tougher material inputs that may or may not be available in recirculated form. In the linear economy, utilization and endurance are in conflict because a product used very intensively will likely be more costly to restore to its original value. In the linear economy, utilization and recirculation are in conflict because very intensely used products may degrade the quality of recirculated material and make recirculation pathways like reuse and remanufacturing more challenging for manufacturers.

Service-based business models may be one solution that harmonizes these three dimensions. In one variation of service-based business model or Product Service System (PSS), **service providers** retain ownership of products, and **customers** pay for temporary access to products (Tukker, 2004). Carsharing is a familiar example. Rather than households going into debt to own a machine they have to insure, fuel, store, and repair, they can instead pay for a service that allows them to access a vehicle when they need it, and to return the car when they don't need it or when they're no longer satisfied with it. When a product no longer suits the customer or the service contract expires, the customer returns the product to its source instead of sending it to the landfill. Therefore the product is *both* enduring *and* reused.

This shift incentivizes the production of high-quality durable goods that are relatively easy to repair. It also incentivizes high intensity use for customers and for service providers, neither of whom want to pay to store items they don't use. An idealized service-based business model incentivizes constant product use, repair, and upgrade, which can be achieved through future adaptive design techniques like multi-layered modularity, continuous service innovation, cascading customer segments. This strategy effectively blends all three dimensions of circularity, and is being applied in a growing number of industries (Nyström, 2019).

Original equipment manufacturers (OEMs) can increase the likelihood that their products will have a long or extended useful lifetime by designing them for durability, flexibility, and adaptability. Designing for the latter two is often referred to as "adaptable design" (AD) (Gu et al., 2009), which involves design for extending product utility by enabling products to be modified in function and/or configuration with relative ease in response to future changes in context for that product. Business models in which a manufacturer or service provider retains ownership over products and sells their function or performance, requires artifacts and products that are designed for value preservation over multiple use cycles. This reduces business-related risks, in particular, the risk of premature product obsolescence.

Future adaptive design (FAD) is a further development of the AD concept that integrates design and business logic borrowed from the CE context (Nyström, 2019). FAD offers a lens for predicting and reducing product-related business risks. Future adaptive products can, through robustness, flexibility, and upgradeability, with new aesthetics, functionality, energy-efficient technology, etc, give the product owner and customer both cost advantages, as well as resource savings, ultimately leading to increased resource productivity.

Measuring the Three Dimensions: Keep them separated!

While accounting for all three dimensions, it is not necessary for circularity assessment tools to collapse all three dimensions into a composite score. In fact, combining all three dimensions involves some compromises. The Material Circularity Indicator (MCI) developed by the Ellen MacArthur Foundation and Granta Design addresses similar dimensions as the three described here, but encourages users to measure either utilization or "longevity" (similar to endurance)— not both. Additionally, the final MCI score—a single number—conceals whether a product's circularity is due to high rates of material recirculation, high longevity, high utilization, or some combination thereof. A product—a pair of blue jeans, for example— could be composed a 100% virgin material, worn incessantly by its user for two months, and then tear at the seams due to weak materials. All the while, one potential application of the MCI could determine that this pair of jeans was a *very* circular product indeed, if its practitioner were to prioritize utilization rather than longevity. Among other challenges, the MCI normalizes dimensions of intensity and longevity with industry-specific averages (e.g. estimated longevity relative to all similar products). It is therefore difficult to use the MCI to compare products or businesses in different industries. The CE Indicator Prototype (CEIP) developed by Cayzer, Griffiths, and Beghetto (2017) assesses companies' potential to achieve the three dimensions, but does not assess all three dimensions directly. The Circular Economy Toolkit (CET) developed by Evans and Bocken (2013) also contemplates all three dimensions, but the tool is better suited as a quick firm-level assessment rather than an objective benchmark.

Moraga et al. (2019) reach similar conclusions about assessing circularity with a set of several indicators rather than a single, composite indicator. In many circumstances, it may make sense for an organization to develop a dashboard that includes measurements for each of the three dimensions before combining them into a composite score. *Kinnarps,* a Swedish furniture manufacturer, has developed the "Better Effect Index"—a dashboard that displays six social and environmental dimensions for each of its products.

Many of the indicators discussed above also present circularity as a dashboard of values in addition to a single score. Some options for assessing each of the three dimension independently are explored below. The examples are drawn primarily from the experience of the authors and are meant to stimulate conversation rather than serve as exhaustive or authoritative examples.

Measuring Material Recirculation

Material recirculation is the most commonly measured dimension of circularity. There are multiple ways to measure it. Metrics can **focus on one or multiple recirculation** pathways like repair, reuse, remanufacturing, or recycling. Metrics can also focus on either recirculated inputs (e.g. how much of my product is made of recirculated stuff), recirculated outputs (how much of my product or my manufacturing waste ends up being recirculated at the end of its functional life), or both. The amount of recirculated "stuff" also has to be quantified somehow, for example, in percentage recirculated mass or in percentage recirculated economic value.

Sustainable Business researchers at RISE (Research Institutes of Sweden AB) have developed and tested a metric that focuses specifically on material recirculation. The metric, called "C", is defined as the proportion of a product's economic value that comes from recirculated material. Simply expressed, C is equal to the economic value of a product's recirculated material divided by its total economic value (Linder et al., 2017). The outcome is a single value between 0 and 1, where a score of 1 represents a product whose value comes entirely from recirculated material, while 0 represents a product whose value comes entirely from virgin material. A particular advantage of the C-metric is that it is not designed for any particular industry, and can thus be applied in a variety of contexts. RISE researchers have worked with the furniture industry, local-government procurement officers, and the automobile industry to apply the metric. Furthermore, a small-scale test using products from a variety of industries presents a clear correlation between high C-scores and low environmental impact, such as climate impact (Linder et al., 2020), so this metric appears to correspond with how many would hope circularity would behave.

Understanding material recirculation alone, however, only presents one avenue toward product circularity. The C-metric offers little explicit insight into *how* a product is used or how well it endures. For this, additional dimensions are necessary.

Measuring Utilization

Measuring utilization is comparably less common, although multiple assessment tools reward use-intensity implicitly by querying whether the product is available as a part of a service-based model (e.g. Evans and Bocken 2013), which have incentives to keep products in use more intensely. The utilization dimension inquires how often a product gets used. An intensely-used product can be thought of as *earning* the embodied energy invested into it. A car driven many miles in a short period of time—for example, a car used in a carsharing service or a taxicab— demands fewer resources *per kilometer driven* than a car that spends 90-99 percent of any day parked. Such an intensely-used vehicle is also less likely to break down due to decay, or to age into social or technological irrelevance. Researchers at RISE have argued that utilization metrics will become increasingly relevant in urban planning and architectural disciplines as a way of accommodating growing demands for urban housing (on one hand) and pressures to conserve energy and resources (on the the other) (Höjer & Mjörnell, 2018). Rather than measure a building's energy footprint per *square meter of space*, the authors recommend normalizing a building's energy consumption *per occupant*. This would encourage more efficient, around-the-clock use of buildings that already exist rather than encourage the construction of new buildings, which require more material and the conversion of green spaces[1].

The MCI (discussed above) integrates utilization by dividing an individual product's estimated lifetime functional units by an industry average number of functional units. For example, a car designed to drive 20,000 km per year when the industry average is 14,000 km would have a utilization rate of 1.43 (20000/14000 = 1.43). This number is plugged into a more complex formula to arrive at one component of the MCI. Of course, it can be challenging to correctly predict functional units for an individual product. The metric also offers no guidance about how to pick the appropriate industry average. Is it best, for example, to compare a car's distance traveled to all other cars in the same country? To cars of the same model? To cars from the same product line? The MCI offers no guidance in this respect.

Measuring utilization is also much easier for products that are easily understood as being *used*. For example, it is relatively easy to measure how much or how often cars, computers, washing machines, power drills, lighting fixtures, parking spots, and clothing get used. It's more challenging to identify how often or how much passive objects like a window, a poster, a street sign, or a houseplant get used. Measuring utilization may require that certain products be considered components of larger assemblies of products, and this may require communication across sectors or new business models to understand segregated products as part of a product package. Accurately measuring utilization will benefit from new and inexpensive sensor technologies that can measure, for example, the number of hours a piece of furniture has been actively used. Measuring intensity of use of buildings and public spaces can take advantage of emerging sensor technology and a revolution in the Internet of Things (IOT technology) to determine, for example, occupants per unit of space over unit of time.

RISE Sustainable Business researchers are considering metrics for utilization based on changes in economic value. The "U" metric—still under development— is defined by the proportion of a product's change in economic value due to being used, rather than changes due to physical decay or exogenous shifts in the marketplace. A washing machine that has been run very intensely because it is serving multiple households will have lost relatively more of its market value due to being used rather than decaying or being edged out of market relevance by a more efficient alternative. This metric works particularly well for products with measurable use and requires comparisons across a sample of other products. More passive products or assemblages of products like interior spaces could be measured as users/occupants per unit of space per unit of time (persons per square meter per hour). These are both still experimental applications.

---

[1] This is especially relevant in Sweden, where the majority (52 percent) of households are individuals living alone. In the United States, single-person households are by far the fastest growing household type, and are projected to overtake two-person households by the year 2030.

Important questions about scale and scope remain with regards to measuring utilization. For example, if measuring the utilization of an automobile, must emerging metrics consider the use of individual components of a vehicle (e.g. seat coverings, windows, mirrors) not immediately related to a vehicle's distance traveled? Should utility metrics also measure the *distribution* of use? For example, is it as important for utilization metrics to acknowledge that certain rooms— or certain *corners* of certain rooms— of a building are used more often than others? These questions may ultimately be determined as much by technological and time limitations of the individuals charged with measuring utility, as by theoretical accuracy and objectivity of a proposed metric.

Measuring Endurance

There are intuitive reasons to measure endurance as a dimension of circularity. A product that retains its value for a long time represents one less product manufactured, fewer resources extracted, and less waste generated. Products can endure because they are better built or perhaps designed to outlast changes in taste or style. As an independent dimension of circularity, however, it remains the least often measured. Multiple assessment tools include subjective questions related to product durability, but such a feature is challenging to normalize in an objective way. The MCI handles endurance similarly to utilization, by dividing a product's estimated lifetime by an industry average, for example estimated lifespan of a hammer divided by the industry average lifespan for hammers. The shortcomings of this approach are very similar to the shortcomings of the MCI's utility measure: it's difficult to predict how long any single product will be used, and there is no guidance about how to determine the appropriate industry average for comparison.

Franklin-Johnson, Figge, and Canning (2016) have developed a longevity indicator that uses units of time to show how pathways of recirculation add to the lifespan of material within a product line. Reuse, refabrication, and recycling elongate the functional lifespan of material. The longevity indicator expresses this in months or years added. Such an indicator might be useful for comparing a product line's level of material recirculation before and after strategic changes within a firm. It could also be useful as way to compare the lifespan of similar product lines in different firms, provided one could access the requisite data from each firm. Yet, despite being expressed in units of time this metric is primarily an indicator of material recirculation as it only indirectly rewards long-lasting products by accounting for its initial use phase.

RISE Sustainable Business researchers have begun to develop a Market Entropy (ME) metric that is determined by estimating the cost of restoring a product to its original market value. It is expressed as <u>one minus</u> a ratio of

a) the total cost of the utility of a product (i.e. the cost of producing the product and the loop cost – the cost for maintaining, repairing and refurbishing a product to deliverits utility) allocated to some random period of time, to;
b) the total value of the utility of a product, measured in sales revenue allocated to the same random period of time.

The higher the score (approaching 1) the more circular the utility, since the value of the utility can be maintained over time in an efficient and cost-saving way. The lower the score (approaching 0) the less circular the utility. A utility with a score below 0 would indicate a utility (or product) that is neither profitable nor circular.

Such a metric encourages long-lasting, high-quality products that are inexpensive to repair. The metric is (unlike the C-metric) especially suitable for products that are sold as a function or service (in a PSS model), since the calculation requires knowledge of both the production cost and the loop cost (for maintenance, repair and upgrade). The latter is normally information known by the owner and user of the product. If the product is owned by the producer and sold as a service, all information needed for the calculation is available with the same actor.

The notion of ‘random time period’ is important, since it avoids deciding a set lifetime at the start of the usage of the product. It also avoids using the notion of ‘depreciation’, since in a circular economy, where value is retained for as long as possible, depreciation could not be pre-assumed. In this way, the ME metric encourages future-adaptive design of products, so that products can in fact retain value and even improve and increase value with time.

What about energy, environmental Impact, and social impact?

A discerning eye may notice that the dimensions listed here make no explicit reference to energy consumption, climate impact, social impact or other impacts commonly associated with circularity or the CE. This is intentional. While customized dashboards and analyses conducted by individual organizations ought to integrate such impact assessments, including any one of these impacts in a heuristic for circularity would strip this relatively simple three-part model of its ability to create a coherent conversation around product circularity. Future scholarship ought to probe the relationship between circularity dimensions and socio-environmental impacts directly, challenging the assumption (and perhaps confirming) that “more circular” equals “lower-carbon” or “socially just”. Recently published findings by researchers at RISE Sustainable Business, for example, shows that products with higher levels of material circularity have lower relative impacts on the environment as measured by lifecycle assessment (Linder et al., 2020).

Measuring Circularity and the Transition to a Circular Economy

A circular *economy* is different than a circular firm—it is a social undertaking achieved by a network of semi-autonomous actors and organizations. A serious regime for circular production and consumption will only arrive on the coattails of documented successes and extensive multisector participation the development of new ‘rules of the game’. Accelerating the transition to a circular economy requires a broad cast of societal actors and institutions to agree to measure, articulate, and mandate verifiable standards. We nominate the three dimensions as a starting point. It is expected that different organizations in different sectors will employ different strategies to improve the circularity of their offering, but a veritable societal transition involves diverse system actors moving in a coherent and mutually-reinforcing new direction (Smith et al., 2005). The three dimensions can serve as a conceptual anchor for OEMs, service providers, public authorities, and researchers interested in making the CE the new reality.

For OEMs, the first step of a transition from a traditional linear “take-make-dispose” business model to a circular business model is to assess their existing product portfolio and identify which circularity dimension will be optimal for each respective product in the portfolio. This should be realized against the existing co-dependencies of different business model elements (i.e. value proposition, value creation, and value capture) which act as a scoping mechanism and put a threshold on *how* and *to what extent* each product can become more circular.

Looking at the home appliances industry as an example, an OEM with multiple product lines might target different circularity strategies for a vacuum cleaner, a refrigerator, or a laundry machine. In 2008, *Electrolux* launched their first green vacuum cleaner made from recycled plastic and since then they have designed a range of green vacuum cleaners that include up to 70 percent recycled plastic. Although recycling has been a successful strategy for increasing circularity in vacuum cleaners, the same strategy presents challenges for white goods as the plastic in a refrigerator is in food-contact and legal requirements hinder material recycling in that product line. Households also tend to prefer to having their own refrigerator at home, so sharing models that could increase rates of utilization may be slow to implement without accompanying transformations in household structure (e.g. collective housing models). Increasing endurance, however, through integrating maintenance and repair services or changing design strategies for increased product durability may yield to more circularity in a refrigerator. For a laundry machine, the OEM might choose a strategy that increases utilization by focusing on product-as- a- service models and rental solutions to target new customer segments. In 2018, Electrolux announced the acquisition of Schneidereit GmbH, a supplier of laundry rental solutions for professional customers in Germany and Austria. The acquisition has enabled Electrolux to add a complementary business model within the professional laundry business.

OEMs can also invest in future adaptive design techniques to increase the likelihood that their products endure in the face of inevitable changes in supplementary technology, aesthetics, demographics, and global economies. Being able to measure and communicate the extent to which their products endure—and whether they have achieved a return on investment through better design—will also be critical to this transition.

Whereas service providers may not have direct opportunities to procure recirculated material like OEMs, they have a special opportunity to advance the circular economy through extending product utility. This involves measuring the extent to which products that they lease, repair, or otherwise use to deliver a service remain in near constant use rather than in storage or otherwise waiting to be used. Benchmarking this progress and communicating it to other actors in a circular ecosystem can accelerate a transition to a circular economy.

Similarly, public agencies responsible for setting procurement standards can require that acquired materials come increasingly from recirculated sources; they can insist that organizations procure services with high levels of product utilization when possible, and set preferences for products designed to adapt to an ever-changing world. This will all require metrics articulated in a way that will allow diverse organizations to adapt. Public authorities can also support product labeling systems. To date, there is no widely used CE labeling standard for consumer products. If managed correctly, product labeling systems for environmentally- or socially responsible products can increase consumer confidence and stimulate price premiums. Product labels can be generated and certified by private firms, by third-party nonprofit organizations, or by public sector agencies. While there are advantages to each of these, research has shown that high public sector involvement in labeling systems stimulates higher consumer confidence (Sønderskov & Daugbjerg, 2011).

Finally, researchers stand to benefit from a consistent measurement framework with built-in flexibility. In recent decades, a multitude of CE metrics and assessment tools have struggled to balance objectivity and practicality: the CE assessment tools that measure the circularity of products and firms with numerical precision often require data that managers are reluctant to release or are otherwise challenging to access. Many assessment tools require expert consultation to complete. Meanwhile, the assessment tools that are easiest and cheapest to apply often involve subjective questionnaires that yield qualitative advice. Such advice may be very useful to an individual manager, but has limited power to benchmark societal progress or compare large samples of products, firms, or other actors. Researchers can take on the challenges of developing inexpensive, objective data collection tools that are sensitive to very specific contexts yet can be used to compare outcomes across an entire economy.

Research Funding

Marianne and Marcus Wallenberg Foundation. Grant Number: MMW 2015.0045

REFERENCES

Blomsma, F., & Brennan, G. (2017). The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity. *Journal of Industrial Ecology*, *21*(3), 603–614. https://doi.org/10.1111/jiec.12603

Campbell, S. (1996). Green Cities, Growing Cities, Just Cities?: Urban Planning and the Contradictions of Sustainable Development. *Journal of the American Planning Association*, *62*(3), 296–312. https://doi.org/10.1080/01944369608975696

Cayzer, S., Griffiths, P., & Beghetto, V. (2017). Design of indicators for measuring product performance in the circular economy. *International Journal of Sustainable Engineering*, *10*(4–5), 289–298. https://doi.org/10.1080/19397038.2017.1333543

Ellen MacArthur Foundation, & Granta Design. (2015). *Circularity Indicators: An approach to Measuring Circularity. Methodology*. Ellen MacArthur Foundation. https://www.ellenmacarthurfoundation.org/assets/downloads/insight/Circularity-Indicators_Methodology_May2015.pdf

Evans, J., & Bocken, N. (2013). *Circular Economy Toolkit*. Combridge Institute for Manufacturing. circulareconomytoolkit.org

Franklin-Johnson, E., Figge, F., & Canning, L. (2016). Resource duration as a managerial indicator for Circular Economy performance. *Journal of Cleaner Production*, *133*, 589–598. https://doi.org/10.1016/j.jclepro.2016.05.023

Gallie, W. B. (1956). Art as an Essentially Contested Concept. *The Philosophical Quarterly (1950-)*, *6*(23), 97–114. JSTOR. https://doi.org/10.2307/2217217

Godschalk, D. R. (2004). Land Use Planning Challenges: Coping with Conflicts in Visions of Sustainable Development and Livable Communities. *Journal of the American Planning Association*, *70*(1), 5–13. https://doi.org/10.1080/01944360408976334

Gu, P., Xue, D., & Nee, A. Y. C. (2009). Adaptable design: Concepts, methods, and applications. *Proceedings of the Institution of Mechanical Engineers, Part B:*

Journal of Engineering Manufacture, *223*(11), 1367–1387. https://doi.org/10.1243/09544054JEM1387

Höjer, M., & Mjörnell, K. (2018). Measures and Steps for More Efficient Use of Buildings. *Sustainability*, *10*(6), 1949. https://doi.org/10.3390/su10061949

Kidd, C. (1992). The evolution of sustainability. *Journal of Agricultural and Environmental Ethics*, *5*(1), 1–26. https://doi.org/10.1007/BF01965413

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Korhonen, J., Nuur, C., Feldmann, A., & Birkie, S. E. (2018). Circular economy as an essentially contested concept. *Journal of Cleaner Production*, *175*, 544–552. https://doi.org/10.1016/j.jclepro.2017.12.111

Li, R. H., & Su, C. H. (2012). Evaluation of the circular economy development level of Chinese chemical enterprises. *Procedia Environmental Sciences*, *13*, 1595–1601. https://doi.org/10.1016/j.proenv.2012.01.151

Linder, M., Boyer, R. H. W., Dahllöf, L., Vanacore, E., & Hunka, A. (2020). Product-level inherent circularity and its relationship to environmental impact. *Journal of Cleaner Production*, *260*, 121096. https://doi.org/10.1016/j.jclepro.2020.121096

Linder, M., Sarasini, S., & van Loon, P. (2017). A Metric for Quantifying Product-Level Circularity. *Journal of Industrial Ecology*, *21*(3), 545–558. https://doi.org/10.1111/jiec.12552

Moraga, G., Huysveld, S., Mathieux, F., Blengini, G. A., Alaerts, L., Van Acker, K., de Meester, S., & Dewulf, J. (2019). Circular economy indicators: What do they measure? *Resources, Conservation and Recycling*, *146*, 452–461. https://doi.org/10.1016/j.resconrec.2019.03.045

Nyström, T. (2019). *Adapative Design for Circular Business Models in the automotive manufacturing industry*. [Licenciate]. University of Gothenburg.

Roos Lindgreen, E., Salomone, R., & Reyes, T. (2020). A Critical Review of Academic Approaches, Methods and Tools to Assess Circular Economy at the Micro Level. *Sustainability*, *12*(12), 4973. https://doi.org/10.3390/su12124973

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., & Kendall, A. (2019). A taxonomy of circular economy indicators. *Journal of Cleaner Production*, *207*, 542–559. https://doi.org/10.1016/j.jclepro.2018.10.014

Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. *Research Policy*, *34*(10), 1491–1510. https://doi.org/10.1016/j.respol.2005.07.005

Sønderskov, K. M., & Daugbjerg, C. (2011). The state and consumer confidence in eco-labeling: Organic labeling in Denmark, Sweden, The United Kingdom and The United States. *Agriculture and Human Values*, *28*(4), 507–517. https://doi.org/10.1007/s10460-010-9295-5

Tóth, G. (2019). Circular Economy and its Comparison with 14 Other Business Sustainability Movements. *Resources*, *8*(4), 159. https://doi.org/10.3390/resources8040159

Tukker, A. (2004). Eight types of product–service system: Eight ways to sustainability? Experiences from SusProNet. *Business Strategy and the Environment*, *13*(4), 246–260. https://doi.org/10.1002/bse.414

Verberne, J. J. H. (2016, February 18). *Building Circularity Indicators: An approach for measuring the circularity of a building*. Eindcolloquium, Eindhoven, Netherlands. https://prezi.com/dtlihektyiwf/building-circularity-indicators/

Zhou, Z., Chen, X., & Xiao, X. (2013). On Evaluation Model of Circular Economy for Iron and Steel Enterprise Based on Support Vector Machines with Heuristic

Algorithm for Tuning Hyper-parameters. *Applied Mathematics & Information Sciences*, *7*(6), 2215–2223. https://doi.org/10.12785/amis/070611