# 2 Does waste equal food?

## Examining the feasibility of circular economy in the food industry

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### Introduction: the (im)possibilities of circular food

Environmental problems, from climate change to biodiversity loss and pollution, are recognized to be caused by an increase in human population, production, and consumption (Victor and Jackson 2015; Sullivan 2020). One of the largest challenges to meet sustainable development is feeding almost eight billion people without compromising the needs of future generations to meet their own needs (Brundtland 1987) and in a more ambitious ecocentric vision, without compromising the other species' survival (Piccolo et al 2018; Washington et al 2018; Taylor et al 2020). This also highlights how our choices as consumers have an indirect consequence on biodiversity.

We are becoming aware that it is impossible to rely on finite resources and that our economy should shift from a linear to a circular approach. The circular economy promises more efficient and effective use of resources and waste, based on the Cradle-to-Cradle (C2C) framework (McDonough and Braungart 2010; Stahel 2016).

However each type of waste has its features and its recycling efficiency might change, making it less "durable" after multiple cycles (Converse 1997; Craig 2001). Provided that energy is added to the process, inorganic materials such as glass, aluminum, or copper can efficiently and indefinitely be recycled and repurposed into new products. Other materials, such as paper or plastic, can be recycled for only a limited time before not being anymore suitable for utilization, resulting in "downcycling" and resource loss (McDonough and Braungart 2010). The food production for a single species causes a deficit in other species' food chains, from top predators to insects down the food chain. Also, packaging "for billions of consumers presents a challenge, especially if the alternative is to be found to petrochemical waste, which is cheap" (*The Economist* 2018). Existing solutions, such as RePack (www.repack.com/news/carbon-footprint-of-reusable-packaging), are not used on a mass scale and do not represent a real alternative to the global industrial economy with mass-scale value chains (Geng et al 2019).

The energy required to recycle makes full circularity a "thermodynamic impossibility" (Man and Friege 2016: 6), and the absolute decoupling of natural resources from economic activity rarely occurs (Victor and Jackson 2015;

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Washington and Maloney 2020). Thus, the optimism about absolute decoupling or upcycling is rarely warranted in the case of consumables.

This is particularly true for the food industry and the waste associated with food production and consumption. Industrial agriculture and animal husbandry present challenges ranging from climate change (greenhouse gas emissions) to biodiversity loss due to the use of fertilizers and insecticides (Garnett et al 2013), exacerbating the need for a sustainable approach to waste management in the food industrial sector.

Different from the aforementioned inorganic materials which can be effectively recycled, the waste from the food industry is mainly composed of nutrients whose composition can vary depending on their source (Jurgilevich et al 2016). The sources of food waste can be divided into two big domains: waste of industrial origin (food loss) that derives from all the processes before the consumer (e.g., production, post-harvest, and processing – approximately 30% to 50% of food intended for human consumption is wasted at different stages of the food system) and waste of consumer household origin (food waste) (Stuart 2009, Gustavsson et al 2011; Jurgilevich et al 2016; FAO 2020). The losses are much more extensive and also include energy, greenhouse emissions, other pollutants, and feces (Ibid).

Therefore, the main objective of the chapter is to explore possible solutions such as the closed-loop systems C2C and circular economy in the context of the food production and sustainability perspective. The sections below engage with C2C principles and the 9-R strategy for the circular economy but also discuss the danger of subversion. Consequently, we turn to Lindeman's (1942) rule and Moerman's ladder. Lindeman's rule states that there is only a 10% transmission of energy from one trophic level to the next. Moerman's ladder indicates how much value can still be extracted from food that is lost. Following that, we discuss alternatives, such as vegan diets, meat substitutes, lab-grown meat, and, in particular, insects. The chapter centers on the question: is circularity in food production possible?

Food waste has a composition that does not allow the same conversion efficiency obtained with inorganic materials. The increased global population further drives the demand for natural resources (Lidicker 2020; Washington and Maloney 2020), and the increased demand for food produces waste. Additionally, industrial agriculture and animal husbandry present environmental challenges due to excessive use of fertilizers and insecticides (Garnett et al 2013). This scenario exacerbates the need to be more effective to implement the circular economy approach in the food sector.

## C2C principles and 9-R strategy for the circular economy: literature review

Circular economy evaluations using the 9-R scale (Figure 2.1) and C2C accreditation and certification are intended to inform producers' choices. These evaluations also address the inputs associated with all the production outputs, use, and disposal, including the product itself, byproducts, and delivery (Ünal and

Shao 2019). C2C identifies three key principles of alternative production systems, starting with *the Waste equals food* principle (e.g., a cherry tree's berries and leaves are nutrients for other species or soil when decomposed). *The use renewables principle* supports only infinite source renewables such as wind and sun. *Celebrate diversity* refers to complex relations within ecosystems. In the biological cycle, the principle of "waste equals food" becomes especially salient (McDonough and Braungart 2010). Yet food, organic material, can hardly be shared between species unless the waste of one species is used as food by others (dung beetles) that contribute to soil formation.

Similar to C2C, a circular economy is based on design principles aimed to eliminate waste and pollution, keep products and materials in use, and regenerate natural systems (EMF 2015). There are various levels of the 9-R hierarchy of circular production. Refuse (R-1) means "doing without," thus stimulating a steady-state economy (Daly 1991) and degrowth (O'Neill 2012; Smith et al 2021).

Notably, in the original hierarchy (RLI 2015; Kirchherr et al 2017; Potting et al 2017), Reduce (R-2) still comes before Re-use (R-3), which is corrected in Figure 2.1 below, as shown by arrows.

Infinite Re-use can be said the best promise of absolute decoupling, satisfying the ultimate goal of the closed-loop systems (Ghisellini et al 2016). Other Rs can counter the take-make-waste system of production and the built-in obsolescence (Bulow 1986). While recovery of metals in electronics has significant sustainability gains (Geng et al 2019), it is difficult if not impossible in the food industry and packaging (Aarnio and Hämäläinen 2008). Refuse (R-1) in food consumption means starvation.

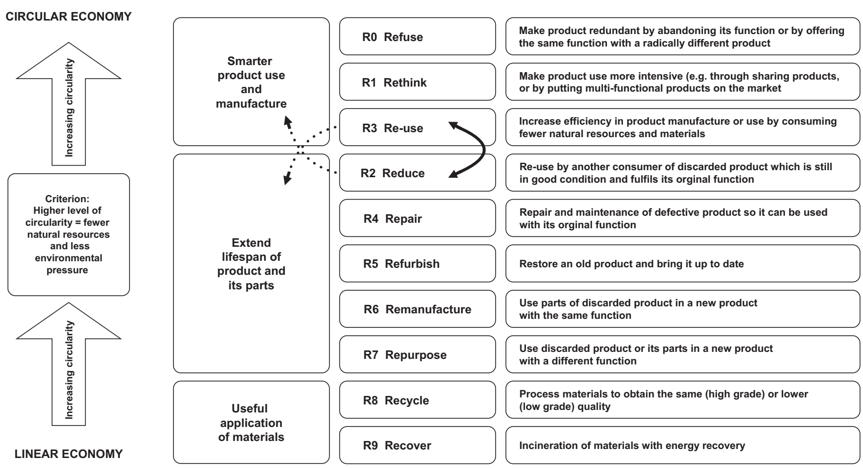


*Figure 2.1* The 9-R hierarchy of circular economy.

Source: Adopted and changed from RLI (2015: 15) and Potting et al (2017) with modifications made by the chapter authors.

The "circular packaging" is challenging since most plastic used today is made of petrochemical waste, which is cheap (*The Economist* 2018). Much of food packaging is a "monstrous hybrid" combining organic and nonorganic materials (McDonough and Braungart 2010). Alternative "organic" or bioplastic packaging is often single-use and requires monoculture plantations (Kopnina 2017). Also, advanced recycling technologies for biodegradable bioplastics are still underdeveloped (Borrello et al 2016).

## The danger of subversion

Yet, not all is green or circular what is so labeled; for example, the ISO CE standards, which are (in some countries) lacking the involvement of all sectors (www.iso.org/committee/7203984.html). The concept of CE (Circular Economy) and its practice has almost exclusively been developed and led by practitioners, that is, policy-makers, businesses, business consultants, business associations, and business foundations (Korhonen et al 2018: 37). Many of the "good practice" companies on the list of the largest promoter of circular economy, Ellen MacArthur Foundation (EMF), focus on continuing production, *not* infinite re-use (Kopnina 2019; 2021). The circular economy is touted as the "new engine of economic growth" (EMF 2015), inspiring optimism but also opening the door for greenwashing.

McDonough and Braungart's book, *The Upcycle* (2013), illustrates unrealistic optimism. Rather than continuously reusing materials as proposed in the *Cradle to Cradle* book, *The Upcycle* suggests that humans can have a net positive effect on ecosystems. This optimism seems unwarranted in the case of biodiversity (Buchmann-Duck and Beazley 2020). While the upcycled food industry may be worth $46.7 billion (Shirvell 2019), upcycling, in this case, refers to companies that, for example, produce beer from old bread, obviously charging more for the former (Kopnina and Blewitt 2018). While the volume of the material decreases in the process of conversion, the monetary value increases – which is not the same as upcycling the original resource (e.g., grain) or contributing to biodiversity conservation.

De Man and Friege (2016) note that in reality waste is rarely "food" due to thermodynamic laws. Producing massive quantities of insects or other food for a single species is unlikely to preserve habitats and food for other species. Thus, claims of circular economy as being ecologically beneficial seem optimistic at best.

## Lindeman's rule and Moerman's ladder

Lindeman's rule in ecology refers to energy flow and nutrient cycling two processes of paramount importance for an ecosystem (Lindeman 1942). Contrarily to nutrients that can be cycled, the energy flow is unidirectional and dissipated while transferred through the trophic levels. According to Lindeman's 10% rule, only a small proportion of the energy intake is fixed into the trophic level and available for the next one. The remaining energy is used by the organisms to maintain the basic metabolic requirements (respiration, maintenance of homeostasis, or investment in growth and reproduction). Therefore the close the trophic level is to the primary production (e.g., herbivores), the lower the solar energy waste is (Lindeman 1942).

Moerman's ladder indicates how much value can still be extracted from food that is lost, thus "the higher up the ladder, the better." Considering Moerman's ladder (cf. Rood et al 2017:33) the greatest value in economic and energy terms is the use of the food product for human consumption. Lower in the hierarchy is the use of these products as animal feed (Lucassen 2019). At the bottom of the ladder is food incineration, a common practice in the agri-food sector (Rood et al 2017). The use of residue streams in a food context is more complex than the conceptual framework suggests as "the devil is in the detail of a production process and the environmental impacts associated with it, as well as any lock-in effects from previous investments" (Rood et al 2017:32). In any policy aimed at promoting a circular economy, it would therefore be sensible to provide room for tailored solutions and flexibility. Instruments are therefore needed which can be used to "substantiate why it would be better to deviate from the 'rule of thumb,' in a particular case" (Rood et al 2017:32). A major problem is that these instruments are still being developed.

## Alternative protein research and products

Even if reasoning starts from the human needs, and not the needs of multiple nonhuman species, considerable effort is needed. These needs are reflected in the "food pyramid" of which some components need more labor and resources, and others less. Proteins often need the most labor and resources for production. However, this is mainly so because of the choice of animal protein as an important source. A lot can be won when we change our diets. If the whole global population would choose a plant-based diet, an agricultural area as big as Africa would be "saved" (Poore and Nemecek 2018).

Several alternatives, including vegan diets, vegetable meat substitutes, lab-grown meat, and insect food, have been developed. The quantity of protein needed can roughly be specified: the average protein needed per person multiplied by the human population is what is needed, given that the recommended dietary allowance has already a safety margin built in (Harvard Health Publishing 2020).

However, a lacto-vegetarian diet with a strong plant-based component seems to be the optimum from the perspective of land use (Peters et al 2016; De Boer et al 2019). In the last decade, many plant-based meat substitutes started to play an important role in consumer choice, justifying billions that have been invested in research (Chiorando 2019). From the nutritional and environmental perspective, a well-chosen vegetarian diet contains all nutrients necessary (De Waart 2018). Meat substitutes offer consumers a balanced diet composed of various ingredients. The same holds for lab-grown meat, which some research showed has no nutritional advantage compared to a well-chosen lacto-vegetarian diet, and it is unclear if it is better than the meat it seeks to replace (Jiang et al 2020).

## Insects

Insects have an excellent nutritional profile (Makkar et al. 2014) and are rich in protein and lipids, and some insect species (*Hermetia illucens*, the black soldier fly, and *Musca domestica*, the housefly) have an essential amino acid profile and protein content that resembles that of fish meal (Makkar et al. 2014). These characteristics coupled with a low environmental impact required for their production (van Huis and Oonincx 2017) make insect-based ingredients excellent sources of valuable nutrients.

One insect species (the mealworm, *Tenebrio Molitor*) has been recently listed among the novel food by the European Union (Regulation 2015/2283) and is thus safe for human consumption. In addition to that, insect meal and insect oil are also seen as excellent raw materials for the formulation of animal feed (aquaculture, poultry industry). The use of seven insect species as ingredients for the formulation of livestock feed formulation has been recently approved by the European Union (Regulation 2017/893).

Many studies suggest that insect-based conversion of organic waste might also improve the management of the increasing problem of food waste (Cheng et al. 2017; van Huis and Oonincx 2017; van Huis et al. 2013). Therefore insects-fed organic waste might represent an excellent solution to transform low-quality organic waste into high-quality feed ingredients.

However, insects are considered farmed animals by the European Union (Regulation 1069/2009) and can be fed neither manure nor catering food waste, ruminant proteins, or meat-and-bone meal. This is to prevent the potential vertical transmission of harmful organisms present in the organic residues which could represent a health risk for humans and livestock. Therefore the current legislative framework impedes the use of insects-fed organic waste for food and feed applications (Pinotti et al. 2019).

Insect-based products can be used also for the production of secondary industrial compounds (e.g., biofuel, lubricants, pharmaceuticals, and dyes) (Fowles and Nansen 2020) whose regulations might be more relaxed toward the presence of specific pathogens. Therefore, despite the insects used to upcycle organic waste might not yet find a safe application in the food and feed sector they could still upcycle valuable organic products useful for different industrial applications.

## Discussion: is circularity in food production possible?

Applying circular economy principles to food production requires, first and foremost, a holistic transformation (Waddal et al 2015) of the food chain. Some Rs from Figure 2.1 are not applicable here but some can be, such as information about what type of energy is used for food production (e.g., growing insects in The Netherlands). There is a big difference between, for example, solar energy and biofuels derived from incinerating wooden pallets or garbage (the lowest R on the 9R scale, Recovery).

One of the larger issues is that the *waste equals food* principle does not apply *after* consumption. In the case of consumables, circularity is impossible without considering what happens to end products. When animals digest food, their waste fertilizes the ground, spreading the seeds. Human toilet waste is hardly used to satisfy the needs of other species, it is either chemically treated and destroyed or burned to produce biofuel, which is the lowest R on the R-hierarchy scale. Refusing food is not an option, but more sustainable (e.g., emissions or water and soil use) or ethical (e.g., animal welfare or labor conditions) food can be seen as a step forward. However, it might be presumptuous (if not to say misleading) to call food circular, especially as feces and urine are not serving as food for endless nutrient cycles.

More indirectly but very importantly, solutions to food shortages include a reduction in the number of people to feed. While the global population has increased due to the advancements in medical and food production technology, we still rely on finite resources (Meadows et al 1972). This reflects on the much-earlier concerns of Thomas Malthus (1826) about the growing population resulting in starvation, war, and disease. Despite the compounding effects of population on global sustainability of resources and food supplies (even if non-human species' interests are discounted), recently much discussion has veered toward consumption in the rich countries (Ganivet 2020). Campbell (2012: 46) points out that the issue of population growth becoming taboo, with the term "Malthusian" becoming derogatory.

Yet, as medical and food production technologies increase life expectancies, it has adverse repercussions on the world's climate and ecosystem's quality, exceeding many of the planetary boundaries (Bogardi et al 2013; Hughes et al 2013). While conscious food movements, including veganism, expanded in some countries, some historically vegan or vegetarian communities (e.g., Hindus) are consuming more meat (Belasco 2014; Devi et al 2014; Pothering 2020), while bushmeat hunting causes the "empty forest syndrome" (Crist et al 2017). Supporting almost 8 billion large omnivores without increasing land conversion for intensive farming and livestock make the interaction between population, food, and biodiversity more pressing (Crist et al 2017; Favre 2019; Shyam 2019), including in mangroves habitats (Boone Kauffman et al 2017). Thus, the population still needs to be considered along with consumption (Kopnina et al 2020; O'Sullivan 2020). Attending to human reproductive rights, avoiding child marriages and unwanted pregnancies through education and information campaigns on family planning offer win-win solutions (Crist et al 2017).

## Conclusions

Making food "circular" presents a specific challenge as what needs to be considered is not just how and where food is produced but what happens to the end product (kitchen or toilet waste). The steady-state economy (Daly 1991) and degrowth (O'Neill 2012) have been particularly challenging in the case of food as the first

R of the circular hierarchy, Refuse, is not possible. Existing solutions for closed-loop or circular food products do not and cannot meet all expectations but can provide a more sustainable way of food production. These solutions are nowhere near absolute decoupling or upcycling, given the complex production chain that also involves the use of energy and land.

The insect industry could offer a promising solution for the sustainable management of food waste. Both the insects (as adults or larvae) or the residual substrate after the larval growth can be valuable resources for animal feeds and fertilizers for crops. However, insects-fed food waste and manure do not yet find a concrete application in industry since they are still limited by the legislation aimed at protecting the livestock and consumer's health. While eating insects is much better in terms of greenhouse gas emissions than livestock farming, it still requires tailored feeds for the insects which take up land and uses energy, making the direct consumption of vegetables still more efficient. All considered, a diet without animal protein, vegan substitutes with high protein value, and ecologically restorative agriculture appear more sustainable practices than insects as food. Further investigation in ecological and health effects (use of pesticides, biodiversity loss induced by monocultures, water use and soil erosion, packaging of alternative products, etc.) and social and political acceptance is needed. Decisive and innovative solutions in food production and food waste management are necessary given the growing population and the shift in eating habits occurring in the aspiring middle classes.

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