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Manuscript

The limits of waste as a resource: a critique and a proposition towards a new scalar imagination for the circular economy model

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In the article, we critically confront the idea of waste-to-resource at the heart of the circular economy. We discuss some of the blind spots and shortcomings of three circular economy principles: designing out waste, emulating natural systems and decoupling economic growth from resource use. We suggest that their limitations are intimately connected to a scalar reasoning ruled by strict, disjunctive categories. Instead, we advance a flat, relational, trans-scalar approach and propose that the potential of a sustained circular economy promise requires a novel scalar imagination attentive to its multiple co-constituted spatialities, social relations and fluid materials.

Keywords: waste, resources, circular economy, scales, flat ontologies

JEL Classifications: R11, Q01, Z1

Introduction

'The *benefits* of the circular economy have been *proven* during the past two decades, *but its application poses some challenges*' (Pacheco-López et al., 2021: 1, emphasis added). This is the first sentence of a recent paper's abstract that examines the generation and assessment of waste-to-resource processes. Statements of this kind related to the current status of the Circular Economy (hereafter CE) are vividly present in academic literature, in international policy directives and visions, as well as in think tanks and foundations—with the most prominent being the Ellen MacArthur Foundation (Corvellec et al., 2022; Murray et al., 2017).[1]

Briefly dissecting the above quote, one can witness the ambivalence regarding the status of a concept promoted as a global practice for the near future: on the one hand, few would disagree that the CE would not be beneficial since its logic is based on approximating natural processes. This has been proven as well, albeit sporadically, with the cases remaining isolated and niche at best (Hofmann et al., 2019; Holmes et al., 2021). On the other hand, applying the CE model indeed poses challenges and has quite a long way to go before amounting to a large-scale, global project. Furthermore, with none of the applications yet actualised at the levels and scales envisioned, no benefits can, at this point, be identified, let alone proven. In itself, this doesn't simply pose *some* challenges for the application of the CE, especially when one thinks of its global reach, but makes the endeavour challenging as a whole on various scales, from households to livelihoods, industries, multi/inter/transnational socioeconomic/technical/cultural/material considerations and all the way to the planetary level.

Notions of circularity have been breeding for several decades now.[2] Some authors identify the very roots of the concept in the late eighteenth century (Lacy and Rutqvist, 2015) through Thomas Malthus' (1798) work 'An Essay on the Principle of Population'. It is perhaps, however, more relevant to associate the sustained interest in the concept since the advent of post-war environmentalism and the paradigm-shifting notion of 'spaceship earth' put forward by Kenneth Boulding (1966), where explicit reference was made to closed systems and circularity.

More than half a century later, the basic premise for a CE remains unchanged: accepting the finitude of resources and therefore minimising their extraction; approximating

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the life cycles of human-made stuff with natural processes; and envisioning such an achievement through an ethics of technology-aided perpetual (re)production of closed loops (Gregson et al., 2016; Murray et al., 2017). When juxtaposed to the current linear economic model of 'take-make-use-dispose', this vision brings forward manifold pressing and crucial questions as to 'how', 'for whom' and 'at what scale(s)' this paradigm shift would become applicable. As a result, scholarly critique of the CE's conceptual basis, potential applicability and core ethics has been proliferating.[3]

Existing critiques have stressed the elusiveness and vagueness of the concept of the CE (Geissdoerfer et al. 2023; Kirchherr et al., 2017; Suárez-Eiroa et al., 2019); undermined the idea of a perfect circle (Skene, 2018; Valenzuela and Böhm, 2017; Žižek, 2010); problematised the dominant technocratic character of CE policies (Friant et al., 2021; Hobson, 2016); and criticised the CE discourse for being overly optimistic (Calisto Friant et al., 2021). In this theoretical article, we add to this stream of critique, yet focus on two heretofore relatively unaddressed aspects. On the one hand, we interrogate the conceptual underpinnings, the logic and the status of waste-to-resource developments within diverse literatures on the CE, from industrial ecology to management, chemistry and engineering. On the other hand, and siding with a handful of works on sustainability, design and the CE that warn of the—often detrimental—effects of colonising and postcautionary approaches (Crocker, 2017; Escobar, 2018), we challenge the predominant scalar thinking that underpins the technoscientific aspirations towards perpetually turning wastes into resources. Let us emphasise that despite the critical tone of the article, we have no intention to dismiss or undermine the scholarly, practitioners' and think tanks' efforts towards less unsustainable and more circular futures. Our aim is rather to provide a modest contribution to the consolidation of the CE concept and its future applicability; we see the article situated temporally within the 'validity challenge stage' of the concept's evolution (see Blomsma and Brennan, 2017: 610). Thereby, as it highlights aspects that we consider to be crucial for the CE debates within social scientific waste studies, the article addresses first and foremost an academic audience instead of explicitly targeting extra-academic ones; we wish to provide existing and future scholarship with orienting questions and propose a new conceptual framework.

Our argument is structured as follows. In the first half of the article, we critically confront the idea of waste as a resource which sits at the core of the EU CE conceptualisation and is concisely contextualised by principles such as 'design out waste' (Ellen MacArthur Foundation, 2013), 'emulate natural systems' (ibid.) and 'decoupling economic growth from resource use' (European Commission, 2020). We focus in particular on the EU CE conceptualisation not only because it forms the main larger regional context of our ongoing empirical work following waste flows but also because the EU's CE initiatives and policies have significantly contributed to promoting awareness of the CE principles and their adoption by businesses, governments and organisations; the aforementioned three principles inform national, regional and local strategies in a top-down manner. We argue that the three principles which circulate widely among academia, EU directives/action plans and think tanks, are ultimately grounded on the expectation to reach a point where waste can be 'undone' into a resource in perpetuity. In this sense, we further argue that, while at present a shift towards the CE model would at best reduce negative environmental impacts, what this model effectively performs is a major *displacement* by substituting the finitude of natural resources with the finitude of waste-turned-into-resources ad infinitum.

In the latter half of our article, and driven by the perpetual waste-to-resource ambition that valorises innovation, novelty and progress while overlooking leakages, spills, inertia, deterioration and decay, we suggest that the shortcomings of the CE are intimately related to the predominant scalar reasoning pervaded by strict, disjunctive categorical thinking. Drawing from flat ontological interrogations within philosophy, science and technology studies (STS) and human geography, we offer a renewed *scalar imagination* for a sustained CE promise, attentive to its multiple co-constituted spatialities, social relations and fluid materials (for related endeavours, see e.g. Davies, 2016). While admitting our inquiry to the multitude of layers and magnitudes that multi-encompassing matters/notions like waste plug into, flow through and traverse, we contend that following such a conceptual scalar orientation would be capable of more appropriately interrogating and evaluating the applicability of the CE's conceptual core.

Waste as a resource and the circular economy

Perhaps one of the clearest manifestations surrounding the obscurity of the CE in terms of its applicability, and therefore inviting further criticism (Figge et al., 2023; Geissdoerfer et al., 2017; Ghisellini et al., 2016; Murray et al., 2017), is that a clear, conclusive definition has yet to be agreed upon. Kirchherr et al. (2017) traced 114 such diverging definitions among peer-reviewed and practitioner sources with, nevertheless with significant overlaps regarding the terms/attributes 'recycling', 'reuse', and 'reduce'. 'Recover', the fourth of the 4Rs that Kirchherr et al. (2017) employed for their coding, and referring to energy recovery from technical materials (e.g. incineration) and biological matter (e.g. anaerobic digestion), was not that prevalent.

It is worth noting that the list of the 4Rs mentioned is under no means exhaustive, adding thus complexity to the strategies and tactics employed towards the

implementation of a CE. Keijer et al. (2019) supported an expanded 11Rs in terms of resource hierarchy: reject, reduce, reuse, redistribute, repair, refurbish, repurpose, remanufacture, recycle, recover and return. What is even more noteworthy, however, especially for the aim of this paper, is that the term 'waste hierarchy', consolidated and legitimised at the European Union level through the Directive 2008/98/EC, is referred to as 'resource hierarchy' in Keijer et al. (2019); waste has magically—at least, and for now, within the content of a scientific paper—attained the status of its positive and invaluable opposite: it has been completely transformed and turned into 'resource'.

Despite the lack of consensus on a unified definition of the circular economy, there is agreement on the urgency to minimise acts of disposal (Kirchherr et al., 2017). This is to be ensued by converting, via an array of ways, whatever could be regarded as waste into resources and feeding them back on the top of the waste/resource hierarchy in continuous loops (Ellen MacArthur Foundation, 2013; Gregson et al., 2015). Accordingly, waste-to-resource (re)configurations frame perhaps the most crucial aspect of a successful transition towards a circular economy (see, e.g. Iacovidou et al., 2017; Romero-Hernández and Romero, 2018; Franco-García et al., 2019; Slootweg, 2020).

But what is the relation between waste and resource like, exactly? As many authors before us have argued, waste is simultaneously relational, dynamic, ambiguous and conventional (e.g. Strasser, 2000; Scanlan, 2005; Kennedy, 2007; Hird, 2012; Blomsma and Brennan, 2017; Cherrier et al., 2018). It is in this sense that Brian Wynne (1987: 1) stated that 'wastes exist in a twilight zone where no clear, "natural" definition of them can be given, within wide margins of uncertainty and variation'. Similarly, some 35 years later Max Liboiron and Josh Lepawsky (2022: 2) added that '[w]aste always overflows its official meanings, and the technical systems designed to manage and contain it'. Waste is not an inherent property of things, but the abstract qualification of a state of degradation, decomposition and decay where stuff is ultimately stripped from the properties that make it desirable to possess and consume, i.e. 'good' to live with.

However, degradation, decomposition and decay are temporal processes of variable duration and pace, and the 'entry' of stuff into the admittedly broad category of waste comes after an—equally variable in intensity—'assembly' of resources. There is no waste without a preceding process of resource manipulation/extraction, much like in nature (Margulis, 1998). Humans, though, are perhaps the only earthlings that have managed to manipulate/extract resources, manufacture technologies for their assembly and disposal, and produce waste in a way that waste and resources are only monodirectionally related. This admission, together with such commonplace statements as 'what is rubbish in one context is perfectly useful in another' (Hawkins, 2006: 10; see also; Lehtonen and Pyyhtinen, 2020) and 'what is considered waste today, can be a resource in the future' (Dijkema et al., 2000: 634) sum up well not only the relation between wastes and resources, but also the starting point for, and aims of, a circular economic model. Effectively, as many as 9 of the current 11Rs (i.e. excluding 'reject' and 'return') are based on transforming waste—including potential waste—into resources either by prolongation or resuscitation of properties attributable to resources.

Designing out waste

There is something fundamentally flawed in how waste is approached in the CE model, granting too much power to human volition and deliberate action. The Ellen MacArthur Foundation states: 'Although it sometimes seems like waste is inevitable in certain situations, waste is actually the result of design choices. There is no waste in nature, it is a concept we have introduced' (Ellen MacArthur Foundation, 2022: para. 3). This heroic statement showcasing human hubris leads to one of the principles—or what we choose to term as 'mantras'—of the CE vision: 'a circular economy aims to "design out" waste' (Ellen MacArthur Foundation, 2013). The logic, therefore, goes that if waste is the result of design choices, then humans can also design it 'out', that is, design systems that do not produce waste as a by-product.

Designing out waste, we contend, ultimately amounts to an attempt to either eliminate decay, degradation and decomposition from the outset or stall them for as long as possible. Such an attempt is doomed to fail since processes of decay and decomposition are inescapable; it is impossible to escape the unavoidable deterioration that awaits all matter (Scanlan, 2005; Thill, 2015). In addition, regarding human design and the logic that pervades it, it has been so far quite emphatically demonstrated that solutions to problems are only temporary; soon, problems, often greater than the ones appearing as solved, consequentially spring from the underbelly of the solutions implemented (Brand, 1994; Deleuze, 1994; Escobar, 2018). Examples abound, and the critique of substitutive practices inherent in design processes can be linked to more general and longstanding debates around solutionist perspectives that celebrate technology as a driver of green transition and ecological sustainability (Caprotti and Bailey, 2014; Hickel and Kallis, 2020). To illustrate our point, however, we employ two characteristic instances that, even though somewhat disconnected, share the same modus operandi.

Current practice globally has it that cars deemed to have reached their end of life are decommissioned. Seventy-five per cent of end-of-life vehicles' total weight, comprising mainly ferrous metals, is recovered through recycling (Maroufi et al., 2018). The remaining 25 per cent, an amalgam of 'heterogeneous and potentially toxic non-metallic' matter consisting of 'plastics, glass, composites, complex materials, fragments and contaminants'

(Maroufi et al., 2018: 261, 262) known as automotive shredder residue (ASR), is destined for landfilling. As Maroufi et al. (2018: 262) mention, this residue of a quarter of a vehicle's weight is expected to increase due to 'constant pressures to reduce production costs and to improve performance and fuel efficiency'. In other words, the need to design vehicles that consume less fuel (i.e. finite natural resources) brought a solution that created a new problem. This new problem appears to have the same effects as the old problem that was solved: it produces a potentially harmful residue. As a result, novel industrial applications are expected to tackle the issue of greenhouse gas, CO_2 and methane that millions of tonnes of annually landfilled ASR have been generating.

Moving to more circular innovative endeavours, the cultivation of seaweeds has been gaining traction recently as a means of sustainable aquaculture (Charrier et al., 2017; Duarte et al., 2022). On 9 March 2023, the winners of the Tom Ford Plastic Innovation Prize were announced, with the first three places held by start-up companies all manufacturing edible, compostable and biodegradable bioplastics from seaweed. As a matter of fact, the second-place winner, Zerocircle, was argued by an academic paper to have 'solved the plastic pollution problem by making biodegradable plastic from seaweed that can be used to package food products' (John and Mishra, 2023: 59966). As much as seaweed aquaculture might be considered the future in terms of plastic film packaging, this same future looks obscure and uncertain in case large-scale cultivation of seaweeds is prompted by growing demand. Iona Campbell et al. (2019), for example, have articulated environmental and population concerns regarding marine ecosystems' capacity to afford such potential large-scale projects.

This, we argue, is the logic inherent to design: as with waste matter, solutions degrade, decompose and decay in the face of current and future challenges; until they flourish again. As much as design might be part of *a* solution, it is simultaneously and inescapably part of *a* problem with variable temporal and spatial ranges. Those ranges vary among unexpected and unforeseen scales. While not sharing the overly polemic tone of Lynn Margulis (1998: 143), we certainly sympathise with the ethical stance:

> '[T]he human move to take responsibility for the living Earth is laughable – the rhetoric of the powerless. The planet takes care of us, not we of it. Our self-inflated moral imperative to guide a wayward Earth or heal our sick planet is evidence of our immense capacity for self-delusion. Rather, we need to protect us from ourselves.'

Thus, designing out anything, especially in the name of nature, requires godlike undertakings of a long-gone modernity and a longer-gone romanticism. Designing out anything is inviting something else by design whose repercussions are unknown, uncertain and inherently problematic. It is simultaneously an act of designing *in*. This 'in' and 'out', however, can only become visible insofar as one becomes receptive to how design and implementation enactments bear the potential to travel from the lab or the office to regional or even planetary territories and back.

Emulating natural systems

This brings us to the second CE 'mantra', that of emulating natural systems. The question of the principal model which the designing out of waste follows relates to the aforementioned idea that there is no waste in nature. The 'mantra' of designing out postulates nature as a sort of master designer that has its ways of rendering waste inexistent. In other words, the admission that there is no waste in nature stems from the observation that natural processes operate in such a way that discarded materials from entities with a life cycle are employed as components that support the subsistence and flourishing of other entities with a life cycle. Accordingly, in the CE, the transformation of wastes produced by human activities into resources is intended to emulate these operations of natural systems, with materials expected to circulate in closed loops. This is not, however, how nature works. It comprises an open, not a closed system; it is sub-optimal, not optimal; it is eco-inefficient, not eco-efficient, and therefore natural systems cannot serve as a viable model for a closed, zero-waste circular economy (Skene, 2018).

To go into more detail, while resource recovery and the idea of closed loops rely on a fundamental separation or disjunction between life/flourishing and death/decay, in natural systems, flourishing and decay are not distinct but inform *one* event. What allows for subsistence and flourishing are multivalent and multidimensional processes where decomposing discards are simultaneously situated and distributed spatiotemporally among entities spread along what scientists call the Earth's critical zone (Gaillardet, 2020). As a result, *there is* waste in nature, even though it certainly is a concept we humans have introduced, and for a good reason: to describe any matter that decomposes and decays.

What is more, decay and decomposition are also processes which *take time,* and therefore, while being vital for flourishing, they do not happen 'by design' but through the self-organisation of systems or, as Tiziana Terranova (2004: 100) suggests, through 'the productive capacities of the hyperconnected many'. They do not unfold in exclusive terms, either, for the benefit of some few, but are situated and distributed in a 'commons' (Hardin, 1968). In contrast to this, the CE model sets design by humans as an imperative, the benefits of humans from this designing as a priority and expects the elimination of decay and decomposition processes to unfold along—and this is crucial—a

combination of a shrunk/vanished temporal pace and a planetary spatial reach (the global CE imperative).

Further, in nature, the process of something becoming waste is initiated by, and results in mutations or, rather, *metamorphoses* of wastes into resources and metamorphoses of entities that share these resources. As Margulis (1998: 148, emphasis added), elaborating on Lovelock's (1972) Gaia, stresses, '[a]ll organisms produce waste', and so 'one organism's waste is another's food', but '*no organism feeds on its own waste*'. So, while all organisms need extraneous resources for their subsistence (no organism could subsist for long by feeding *only* on its own waste), curiously, the CE model is based on an exactly opposite ambition. The transformation of wastes produced by human activities other than eating and excreting are expected to circulate in closed loops where, through processes of disassembling, reassembling, separating and purifying, resources are obtained.

To speculate, even though Margulis (1998) refers to organic processes of feeding and waste production, it is difficult to imagine humans stripped from the multitude that keeps them and their desires going, and therefore sustains them, feeds them; we are without doubt referring to the devices, machines, furniture, objects, clothes, buildings, infrastructures—and hence all industries—that have brought humanity to its current condition. At the same time, to stick with the speculative argument for a while still, it is perhaps even more difficult for Western or Westernised humans to imagine eating and excreting outside the operational boundaries of these industries. If natural systems were to be emulated, the CE model would need to be revised, perhaps radically. Regenerative practices cannot overlook the critical mass of sociotechnical entities sustaining humans and with it, the interdependencies, alliances and heterogeneities that unfold at multiple scales and are forged by the relations between organic and inorganic elements.

Decoupling

The appeal that acts of purification and segmentation exert on the CE model is also expressed in the third 'mantra' examined here, namely the decoupling of economic growth from resource use. Here, 'resource use' refers explicitly to the extraction of virgin natural resources. The fact that sustenance, let alone all kinds of growth—including that of the economy—and resources are interdependent does not require further elaboration. As a result, the hypothesis of wastes becoming resources in perpetuity is again at the forefront of the 'decoupling' aspiration.

Would it be possible, however, to ground this decoupling aspiration realistically? Drawing from relevant challenges identified so far in current literature, we wish to address two aspects regarding the decoupling 'mantra', focussing specifically on waste-to-resource considerations. First, the economic growth envisioned is only possible insofar as the newly discovered, often referred to as 'untapped' (e.g. Langan and O'Toole, 2017; Pham et al., 2015; Vaish et al., 2016) resources from waste are sufficient. This can only mean two things: either that the current global waste stocks are enough for the remainder of humanity's existence on the planet—which cannot be true and substantially contradicts the CE principle of emulating natural systems; or that waste will have to be produced in new quantities and distributed by new flows to cover the resource demands of the increasing human population—which, as we shall show below, contradicts the CE principle of designing out waste.

For the principle of decoupling to work, instead of being eliminated, waste would rather have to flow in abundance as a resource panacea. This brings us back to the problem of resource scarcity. For a possibility to exist so that humans can not only perfectly emulate nature but also accelerate and appropriate for their benefit what takes time and is distributed across the planet—the process of decay/flourishing—some sort of simultaneous energetic abundance and preservation would be required. It has long been established, however, and this is also one of the CE model's criticisms regarding the decoupling 'mantra' in relation to the second thermodynamic law, that energy—and hence resources—is not infinite and cannot be contained (Cullen, 2017; Daly, 1996; Georgescu-Roegen, 1971, 1979; Giampietro, 2019; Giampietro & Funtowicz, 2020; Skene, 2018). It is a well-established fact in scholarship that nothing is infinitely recyclable, and every cycle results in quality degradation (see, e.g. Cullen 2017; Korhonen et al., 2018; Shyns and Shaver, 2021).[4] There is always a remainder, an excess, that leaks and escapes human technoscientific ideals and business models.

This remainder, an entropic product, translates into numerous sociotechnical, -material, -cultural and -political enunciations: trade-offs, downgrading, physical material losses, greenwashing, and so on. Mario Giampietro (2019) has vividly demonstrated that economic growth requires an accelerated pace and density of flows in relation to the pace and density of flows of natural processes. In other words, it unavoidably results in resource scarcity, regardless of whether the resource in question is natural or fabricated/manipulated/disposed of by humans (Vadén et al., 2020).

The second point we wish to address is related to the fact that economic growth decoupled from the use of finite natural resources can only be relational, executed at the expense of others, and if so, the envisioned closed loops must also be territorially bounded (national, regional but under no circumstances global or planetary) and of questionable duration. Up until now at least, the CE has largely been an instrument for rich countries to make money from overconsumption at the expense of poor countries, leading to global inequality and to what some

have provocatively called 'waste colonialism' (Liboiron, 2021). This imposes questions such as: who would benefit from a circular economy based on pursuing economic growth while following the decoupling 'mantra', and who would be left out?

Waste recovery through trading and recycling is currently a thriving multibillion global business with countries of the Global North being the key exporters and those of the Global South the key importers, with China having been the main one until the 2017 implementation of solid waste import ban (Gregson and Crang, 2015; Wang et al., 2020; Wen et al., 2021). Even after China's ban, the routine has not significantly shifted; exported waste streams have been diverted to other prospective pollution havens in Asia, Europe and the Pacific region (Qu et al., 2019; Tran et al., 2021). EU policies and directives promoting the CE, however, wish to close the loop and keep the waste trade flows strictly within the Community's boundaries (Gregson, 2023; Gregson et al., 2015). Perhaps under the guise of a moral imperative that global waste trade is an illegal and dirty business turning the Global South into the planet's dump (Gregson and Crang, 2015; Gregson et al., 2016), Europe's plans for economic growth include recovering waste materials as secondary sources and retaining them within continental production-consumption chains. As a result, the 'mantra' of decoupling stands in direct opposition to the aspiration for the CE's global application.

These two instances in relation to decoupling—the continuous transformation of wastes to resources and their territorial bounding—are based, we contend, on an elementary but crucial *displacement,* which is no other than the human extraction of secondary resources instead of primary ones. This displacement could only happen through the translation of waste to resources, of the non-valuable to the (in)valuable. At the same time, and since this translation is envisioned as a rapid, disjunctive and purifying process, the displacement sits also at the core of the two other CE 'mantras' examined, namely the designing out of waste and the emulation of natural systems. Most importantly, this displacement from natural resource extraction to waste-as-resource scavenging takes place due to the limitation inherent in the CE concept's architecture to grasp how manifold processes are interrelated and how they unfold spatiotemporally.

We thus identify as one of the main obstacles towards a less anthropocentric, more earthly and more inclusive concept of the CE the challenge to think about processes that happen simultaneously within global reach, within miniscule, molecular levels and, most importantly, within the infinite strata, levels and layers in-between. Even though the three 'mantras' interrogated in this section partially overlap, there remains a rigid segmentation between the main scalar constructs the CE model is based upon: the *social* (designing out), the *environmental* (emulating) and the *economical* (decoupling). What is more, this segmenting logic is further accentuated by the—equally scalar—epistemological division of labour regarding issues that happen at the local, regional and global levels.

Thinking about the above separately is unfortunately not sufficient for a truly circular conceptualisation. The household, the chemical element, the polymer, the commodity, the industrial plant, the 'industry' as a whole, the 'regional' of any sort, the 'earthly' in its entirety are all embedded within each other and variably interrelated. These are all matters entangled with both scalar imaginaries and the worlds of waste that can no longer be ignored. There is no Away to which rejectamenta could be expelled for us to carry on our wilfully ignorant lives (Thill, 2015), but the world of humans is inextricably entangled with waste. If stuff is to circulate, this means it has to flow, change and adapt within a manifold of scales, levels, magnitudes, layers and strata. Prior to designing out waste, emulating nature and decoupling resources from growth, we need to attest to how these wastes/resources are present and active in the multitude of scales we choose to keep separate. We explore this in the following section.

The multiple scales of waste

Mutable mobiles, or a call towards enriching scalar imagination

The imperative of bounded resource recovery, which was critically scrutinised in the previous section, is also fundamentally a matter of *scale*. This is evident in the definition provided by Kirchherr et al. (2017), which is perhaps the most comprehensive definition of the CE model to date. It portrays the CE as 'operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations' (Kirchherr et al., 2017: 224–225).

Recent scholarship has been increasingly engaging with the topic of scale in relation to the CE. On the one hand, macro-approaches have examined the potential applicability of the CE at the level of regions (Alonso-Almeida and Rodríguez-Antón, 2020; Avdiushchenko, 2018; Henrysson and Nuur, 2021; Obersteg et al., 2019; Towa et al., 2021). Specifically for countries and regions of the EU, the degree of promotion and implementation of strategies, directives and incentives is at the centre of such macro-inquiries (Luttenberger, 2020; Mhatre et al., 2021; Scarpellini et al., 2019; Strat et al., 2018; van Buren et al., 2016). Insofar as accomplishing the CE transition requires a *systemic* change (Linder et al., 2017; Velis, 2018), overcoming the global challenges for the success of the CE model is argued to require an incremental approach of gradual interconnections between regional and

subsequently national levels of implementation until the planetary scale is reached (Strat et al., 2018). On the other hand, researchers have also insisted on the importance of paying at least equal attention to the *micro* level, with an emphasis, for example, on more spatialised accounts of everyday practices and consumption (Cherrier et al., 2018; Hobson, 2016, 2020; Holmes, 2018; Rogers et al., 2021) or on the role of networks of building a socially integrated CE at the local scale (Pusz et al., 2023).

Barreiro-Gen and Lozano (2020) and Kristensen and Mosgaard (2020) have observed that the majority of research on the CE has so far focussed on the macro (e.g. regional, national, and global) and the meso (e.g. industrial networks) levels, whereas detailed scholarship on the micro level (e.g. companies, households) remains scarce. Still others have stressed the need to rethink the macro-meso-micro triad, and the significance of local conditions as both enhancing and limiting factors (Arsova et al., 2022). A successful CE transition would thus require the alignment of practices on different spatial and social scales: in addition to policies, regulations and laws on both national and international levels, the transition is also dependent on households, companies and public bodies sorting and recycling their wastes under those policies, regulations and laws, and this is again conditioned by a functioning waste infrastructure.

We suggest that neither increased attention to mundane micro-practices and interactions nor embedding richly described local scales in larger regions and, ultimately, in a global system is enough to produce a balanced picture of the challenges and crucial planes of the CE transition. Instead, we advance a relational, trans-scalar approach that refutes the macro-meso-micro triad and problematises the idea of the 'local' and the 'global' as categorical givens. What is more, we hold that it is important not to interrogate the different scales separately, but one must attend to their co-constitution and interconnections.

A polyethylene terephthalate (PET) bottle, typically manufactured for single use as a container and therefore treated as a disposable object, provides a quite characteristic example of the interconnectedness of various scales, and of how things traverse those scales through their heterogeneous and differential alliances. A wide range of global/international/national/regional/local regulations, standards, labour and concerns are folded into the PET bottle's shape (e.g. Demirel and Davel, 2009), disposal, recycling and reuse (e.g. Feron et al., 1994; Welle, 2013; Gopalakrishna and Reddy, 2019; Pinter et al., 2021). Even before its acquisition by the consumer, it has travelled extensively from (global)—millions of years old—crude oil extraction to (national/international) labs for testing and certification, to (global/national/international/regional/local) industries for fabrication and further to (global/national/international/regional/local) retail chains. Later in its lifespan, as a disposed object, it can end up in municipal plants after being sorted out for recycling, exported internationally as a potential resource, used to produce post-consumer recycled PET (rPET), employed for greenwashing, hidden behind a bin, turned into a lamp, thrown into the water, or decomposed as microplastics particles temporarily inhabiting the oesophagus of a living organism, to name just a few of its potential trails. PET and rPET are thus woven with various temporalities, locations, elements and activities, and they enact new kinds of social, cultural, political, technoscientific, economic and ecological practices and relations (see also Hawkins, 2013; Hawkins et al., 2015). Is a (r)PET bottle thereby local or global? National or international? Microscopic or macroscopic? Or does it exist at a meso level? Our answer is none of the above. These familiar scalar categories evidently cannot capture the complexity described above. What is needed, therefore, is a different kind of scalar imagination.

Even though points of reference and loci of observation are required to establish even the most elementary communication, reductionism is unavoidable if scales are taken for granted. This reductionism, however, is not the mere result of scales being taken for granted. It is also closely associated with the significance attributed to a few scalar constructions at the expense of others within their observable plane. We, by contrast, propose here a methodological move towards observing and following things and materials with multiple, shifting attributes on their paths towards traversing, inhabiting and reconditioning/recomposing scalar constructs.[5] This move insists on giving sustained attention to the differential associations and processes between and across various scales, without, however, treating the latter as predetermined, fixed containers, and is thereby a call for the enrichment of scalar imagination.

It is admittedly quite laborious an attempt to revise the notion of scale along these lines, as scale itself seems to presuppose the existence of magnitudes ordered in a hierarchical, either vertical or horizontal, manner. Either distinguishing orders of magnitude between identical entities or constructing aggregates of heterogeneous ones through their spatiotemporal reach, scales intrinsically perform a *distribution*: a simultaneous unification and division, be it nested or otherwise. Whether operating in the realm of dualism—such as 'micro-macro' and 'local-global'—or in a sequential succession—for example, 'Planck length-…-organism-…-planet-…-known universe'—ultimately makes no difference. What is decisive is the problematic hierarchy (indeed, vertical, horizontal, or both) that scalar thinking imposes. The hierarchical understanding of scale is further coupled with 'zoom effects'—jumping freely from one scale to another—(Latour, 2017), which we find equally problematic, as things do not travel from one scale to another without laborious work and without changing.

It is perhaps due to the problems related to presupposed magnitudes inherent in the notion of scale that

Marston et al. (2005: 426) propose its dismissal altogether and instead advance the notion of 'site' that 'inhabits a "neighbourhood" of practices, events and orders that are folded variously into other unfolding sites'. In a different attempt, but through similar 'flat' ontological principles, Latour (2005) devotes most of the second part of his introductory book on Actor-Network Theory to prescribe an ameliorative methodology based on following associations between broken down nodes and lines of action, ultimately leading to a descriptive composition of emergent, stabilising categorical formulations. What both of these works easily bypass, however, is the unavoidable affinity scale shares with the notion of 'category'. We consider this a crucial point, and even a point of departure if one endeavours to refine scalar perspectives, especially when it comes to waste studies and scholarship on the CE. For this reason, while embracing several of the insights of both Marston et al. (2005) and Latour (2005), we propose a differentiated Deleuzian/Spinozist take that will help rethink matters of scale and disentangle them from their reliance on categorical (de)limitations (see Deleuze, 1988; Spinoza, 1996). What distinguishes the proposed approach from other multi-scale ontologies, such as DeLanda's (2006), is the refusal to compromise between a cosmic spectrum where extensive *attributes* (variable orders of magnitude) intermingle—and become simultaneously entangled with intensive attributes—and a specified structural/sociological understanding of scale merely based on ascending orders of magnitude.

Things like a PET bottle are in a constant state of motion and rest. The bottles are neither immutable mobiles (Latour, 1986) as certain objects have been analysed, nor mutable immobiles (Guggenheim, 2009) as buildings have been scrutinised. They are rather *mutable mobiles*, transferers of shifting properties. They travel from here to there, mutate, accumulate, form/deform/inform other attributes and aggregates of attributes; they effectuate individuations (Simondon, 2020) and can be detected through their folding into, or plugging into, processes they set in motion (or rest). In the same way they traverse categories (e.g. from a container holding the liquid to hazardous waste and to raw materials for downcycling) through their mutations and alliances, and render them mutable or momentarily stabilised, mutable mobiles not only traverse scales but also *re/de/construct* them through differentiation.

Because of the emphasis on the production of scales, the approach that we propose has many resonances with Marston et al'.s (2005) and Latour's (2005) work. There are, however, two analytical considerations that differentiate the concept of mutable mobiles from the 'sites' of Marston et al. (2005) and from Latour's (2005: 165) instructions on 'how to keep the social flat'. First, as already hinted, we do not propose a total abolition of scales as Marston et al. (2005) do; we contend that scales, like categories, can be helpful constructs in the research on the CE as long as they do not pose *a priori* limits to the inquiry. In other words, the planes in which mutable mobiles perform are only to be discovered. Second, we do not share the prescribed methodological fascination of Latour (2005), endemic in Actor-Network Theory and quite often framing STS inquiries, to start from the identification of 'controversies' and conclude with an account that shows how things are held together. We assert that following mutable mobiles can be much more unpredictable and surprising than delimiting (scaling) the process of following. As much as mutable mobiles are fascinating to identify moments of stabilisation, they are equally potent in tracing moments of escape and the multiple interchangeabilities of flow and stasis, something which the tendency of waste to escape and resist the efforts to manage, govern and tame it illustrates well.

While the CE, as we intimated above, is currently measured on indicators placed on the three levels of the micro, meso and macro (Kristensen and Mosgaard, 2020), we maintain that such rigid scalar prescriptions are all too crude and impoverished conceptual tools to attend to the richness and messiness of the world and flows of waste. As evidenced by the example of the PET bottle, waste materials and their fluxes are much too heterogeneous and messy to fit the pre-given compartmentalised categories offered by predetermined scalar labels (typically understood through the cognitive schema and spatial metaphor of the container). On the contrary, things become mixed through their attributes' escapes and returns that remake them, that with them remake the categories themselves and therefore offer ever-shifting scalar constructs. The scales in which waste, resources and waste-to-resource practices exist *and* participate in constituting are much more multiple than those of the micro, the meso and the macro. They range from minuscule materials (e.g. molecules and microplastics) and sub-individual flows to transnational, global processes, to processes whose scales remain to be discovered (for a rebuttal of the micro/meso/macro model, see also Pyyhtinen 2015, 2016, 2017).

Therefore, instead of jumping from the micro to the macro and back, the kind of scalar imagination that we insist on emphasises the need to form a chain as continuous as possible of the thousands of tiny conduits linked to one another.[6] When analysing the transformation of waste to resource, one should travel along these conduits and follow through what kind of terrain and which sites they lead and pay attention to what kind of entities and materials are involved in their weaving. The problem with the spatial abstraction to which the vertical/horizontal hierarchisation of predetermined scalar distinctions (such as the micro-macro) leads, and upon which the concept of the CE is ultimately founded, is that it ignores the laborious work of mediation and misses crucial steps. Instead of being pregiven, scales are produced and sustained. What is more,

mutable mobiles are encompassing enough as a concept to embrace not only human attributes that effectuate and maintain scales, but also various non-human ones such as technological, inorganic and geological—to name a few—that participate in scalar re/de/compositions. However, through their potent and wide reach, mutable mobiles are not limited to merely spatial dimensions and intensities; they equally afford being followed through temporal trails and variations, and equally produce, sustain and transform temporal scalar constructs. This is what we examine in the following final section of this paper.

Timescales

When referring to attributes and their capacity to have effects on scalar constructs, the concept of mutable mobiles is in line with Deleuze's (1994) descriptive notions. What differentiates descriptive notions from (scalar) categorical thinking falls first within the distinction between nomadic and sedentary distributions (ibid). The analogy here is immediate with what is mentioned above and thought of in spatial terms: categories (and scales) are distributed in a sedentary fashion, first segmenting what is distributed and then redistributing it by imposing rigid boundaries between segments (ibid). Descriptive notions, by contrast, respond to a different process by which space is never segmented-distributed, only momentarily occupied in a nomadic manner of perpetual movement.

The second aspect that distinguishes descriptive notions from (scalar) categorical thinking is based on another distinction Deleuze (1994) makes, this time between the virtual and the possible: the possible is predetermined, while the virtual encompasses all the potential of that which has not yet been actualised. To keep up with what was mentioned before, the virtual is in a sense responsible for the mutable and the hybrid, that which does not fall into the realm of prediction. Therefore, besides affording the movement between categorical boundaries, descriptive notions also attend to a world of potentiality rather than possibility.

This second aspect of descriptive notions, and hence the concept of mutable mobiles employed as such, unavoidably leads us besides spatial-scalar considerations to temporal-scalar ones. Drawing from Deleuze (1994), Marston et al. (2005) also note the distinction (although slightly differentiated from our above formulation) between the 'virtual' and the 'actual' but dwell on it strictly in spatial terms. The multiplicities and potentialities, however, inhabiting the real, i.e. both the virtual and the actual, are inextricably linked with time. The following quote from Deleuze's (1991: 38, emphasis in original) *Bergsonism* is illuminating in this sense:

> 'The important thing here is that the decomposition of the composite reveals to us two types of multiplicity. One is represented by space (or rather, if all the nuances are taken into account, by the impure combination of homogeneous time): It is a multiplicity of exteriority, of simultaneity, of juxtaposition, of order, of quantitative differentiation, of *difference in degree;* it is a numerical multiplicity, *discontinuous and actual*. The other type of multiplicity appears in pure duration: It is an internal multiplicity of succession, of fusion, of organization, of heterogeneity, of qualitative discrimination, or of *difference in kind;* it is a *virtual and continuous* multiplicity that cannot be reduced to numbers.'

What we are aiming at with the notion of mutable mobiles here is an analytical move towards the decomposition of the composite; not in terms of breaking entities down to their parts, but of rendering visible their multiple mutations and alliances over both space and time—and therefore of the multiple scalar dimensions/constructs they occupy. Since all entities have what we are used to referring to as lifespans, spatial reach cannot be examined separately from time, duration, motion and rest, speed and slowness. And this precisely is the significance of the art of noticing (Tsing, 2015) and following attributes: the temporal scale 'lifespan' becomes not only relational, but also assumes a reach that allows it to upend anthropocentric conceptions of time ubiquitous in the social sciences. Attributes as mutable mobiles traverse, compose and, most importantly, decompose and recompose entities and their assumed lifespans. They have this virtual spatiotemporal capacity to inform them in unpredicted, unexpected ways where life, death, flourishing and decay become entangled in perpetuity, in a continuum of difference.

We have already hinted at the above with the example of the PET bottle, a remarkably durable material entity: its lifespan (that is, the time required for the plastic polymers of the bottle to degrade) can last from decades to hundreds of years (Ioakeimidis et al., 2016). The attributes of the PET bottle's lifespan, whose distribution by far exceeds most organic (and human) life expectancies, have already shown their capacity to mingle with, affect and become affected by entities spanning from organisms to ecosystems. Some of these entanglements' effects have actualised, while a multitude of others remains in the realm of the virtual. These attributes of the PET bottle also plug into policies, regulations and their amendments (therefore their lifespans) related to disposability and recycling. They give new lifespans to international frameworks, visions and ideals, with the CE being a prominent example. They fold into them, as containers of drinkable liquids or as DIY plant pots, the sustainment, flourishing and decay of mundane lifeworlds, to name, once more, just a few of the lifespans with which attributes of the PET bottle become entangled. In other words, as much as attributes endure, they also affectively enhance and diminish multiple associated durations, lifespans and temporal scales, be they virtual or actual.

Conventionally, the social sciences tend to be preoccupied with the present, and when social scientific studies have paid attention to long temporal sequences and processes, they have typically studied the past, more or less ignoring the future (for exceptions, see, e.g. Beckert, 2016; Ialenti, 2020). However, as we argue, to grasp the presence and effects of waste as a mutable mobile across—and beyond predefined—spatiotemporal scales as well as the challenges it poses, it is not enough to follow its multiple scalar manifestations only in *spatial* terms.[7] It is equally important to also attend to its various *temporal* scales. The persistence of, for example, plastic—as briefly sketched above—or nuclear waste, and their effectivity for remarkably long periods, calls for incorporating relational and overlapping timescales into social thought.

Furthermore, acknowledging how our present actions extend to the future and how anticipated futures shape present actions, we consider it crucial to incorporate the anticipated waste futures of consumer objects into their analysis within the CE framework. These anticipated waste futures are present already in the presence of the commodities before they are turned into waste, in the analyses of their production, consumption and use. This dimension of the future can be conceptualised through the notion of *deep time* (Ialenti, 2020), used more commonly in geology to refer to geologic events which have a time scale significantly greater than that of human lives and plans (Hora and Von Winterfeldt, 1997; Wilkinson, 2005). Importantly, as we have already noted, the wasteness of plastic packaging, for example, does not appear only after it has been disposed of, but it 'seems to be inscribed in its form and function, in its smooth surface, in its very plastic materiality' (Hawkins, 2017: 18). The deep time of the discarded material is folded into the material and our relations with it from the very beginning, and it is important to take this temporality into consideration. Waste is what will be left of us; it is the material residue of our existence and civilisation. It is in and through waste that our present persists past its term.

Conclusions

In this article, we critically interrogated the concept and model of the CE in relation to the transformation of wastes into resources, an aspiration that sits at the core of the CE vision. We did so by paying attention to three of its main principles within the EU: designing out waste, the emulation of natural systems to achieve regenerative outcomes, and the decoupling of economic growth from (natural) resource use. These principles which inform and steer national, regional and local strategies in a top-down manner have often been employed in current academic literature on the subject, and they can be said to have acquired the status of 'mantras' among think tanks and EU policy narratives.

We confronted and critically assessed these three CE principles and identified their conceptual and practical shortcomings that, as we argued, result from an elementary *displacement* performed by the prevalent CE model: the rapid elimination of waste and its perpetual undoing/reversal into resources as a means of substitution for natural ones. First, the admission that there 'really' exists no waste in nature, but waste is a human construct creates a disjunctive illusion that the inevitable temporal processes of decay, deterioration and decomposition—processes that are also the precondition for flourishing—could be effectively done without. Second, the approximation of regenerative natural processes in relation to resource-making is founded on a logical leap that discounts the distributive properties of waste generation; humans cannot sustain themselves through the infinite reversal of their own waste into resources and for their own benefit. Third, and besides the fallacy of a stable equilibrium where dissipation, leakage and loss can be controlled, closed loops are simultaneously territorially bounded loops destined to further accentuate inequalities, ultimately undermining the CE model's vision for a global reach.

We argued that the above issues stem from an epistemological division of labour when it comes to thinking about and approximating matters of scale. We suggested that neither increased attention to mundane micro-practices and interactions, attending to meso-level phenomena, nor embedding richly described micro scales in a macro (regional, national, international, or global) system are enough to produce a more balanced picture of the challenges and crucial planes of the CE transition. We advanced a flat and relational trans-scalar approach that refutes the macro-meso-micro triad and problematises the idea of the 'local' and the 'global' as categorical givens by emphasising the terrain of the in-between. The article is thereby a call towards empirical research that, through employing the conceptual tools elaborated above, would be able to explore this in-between terrain without jumping scales. Not only does such an approach insist on the multiplicity and messiness of scales, but it also attends to how waste materials are mutable and mobile, traversing categories and scales, both spatial and temporal.

Mimicking/emulating attributes observed in nature (though only imperfectly) is a staple in human existence, from canes that add limbs to planes that give wings. Emulating natural processes, however, involves aspects that are nowhere apparent on the planet, at least at the level of complicatedness employed by humans; it involves regulating, moralising and normalising through sociotechnical, -material, -cultural and -political assemblages. What is more, the planet is an open-bounded entity that operates under unpredictable relations that strengthen and diminish potentialities both between what exists within and outside. Such relations are also shifting

in paces/rhythms that are variable and of variable reach. This is how natural cycles/processes operate to the best of human knowledge.

To be able to assert whether a CE would be feasible, we would first need to know how matter, including waste, relates to the manifold of levels of such cycles/processes which follow variable, different and differential paces and tempos, yet are (inter)related owing to the flows of materials that make them. To do that, we need to imagine, practice and enact processes that include humans but do not revolve around humans nor can be approximated as projects subjected to human control. If the CE requires a systemic change, perhaps the starting point would have to be a more grounded and modest ethics of how humans relate to nature. This is also where an exercise into novel scalar imaginaries of waste would prove beneficial. Investing in such an exercise through a relational, situated ethics unavoidably brings one towards the revision of the three mantras examined and reassessing what kinds of initiatives and interventions are realistic and feasible in the first place. Therefore, despite the theoretical nature of our endeavour, we believe the article has potential implications for practice and policymaking. Among other things, understanding the limits of waste as a resource and the manifold scales it assumes and enacts suggests that incentives, provisions and directives would need to dwell in a broader terrain than 'an economic system that is based on business models' (Kirchherr et al., 2017: 224) and tackle, rather than align with, the essential contradictions upon which the CE model is based.

With our critical inquiry into the aforementioned 'mantras', we certainly did not wish to devalue or undermine the CE model as such. On the contrary, like many others, we trust that it bears the potential to bring about a decrease in natural resource extraction by prolonging the lifespan of usable matter. A crucial aspect that remains to be interrogated, however, is to what degree, to what magnitude and for how long this could be effective. This is also an urgent practical and political question of scale, calling for our attention to territorial rhythms and timelines. Could one enact the CE at a planetary level? And, if this is the ambition, can Gaia support such an endeavour? At what cost? And for how long?

Endnotes

1 Being a UK-registered charity, the Ellen MacArthur Foundation, established in 2010, has played a key role in popularising and campaigning for the idea of the CE, while utilising concepts from seminal works such as cradle-to-cradle design (McDonough and Braungart, 2002) and biomimicry (Benyus, 2002). Its influence is partly discernible also in how it is commonplace for scholarly works on the CE to reference the foundation's reports as authorised sources.

2 For extensive accounts on the history of the concept and relevant narratives/discourses, see Crocker (2018), Lacy and Rutqvist (2015) and Blomsma and Brennan (2017).

3 For a comprehensive review of the current critique surrounding the European conception of the CE, see Corvellec et al. (2022).

4 So, 'when ecology insists on the existence of limits, economic sciences find a way to invent a limitless future' (Latour, 2018: 120).

5 For more of the follow-the-thing methodology, see, e.g. Appadurai (1986); Kopytoff (1986); Evans (2018); Woodward (2019); Holmberg and Ideland (2021).

6 This is an important point we take from Latour (2005; 2017).

7 A dimension with which, as mentioned above with the example of Marston et al. (2005), the discussions and debates around scale in human geography have almost exclusively been preoccupied.

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