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Efficiency, "watts" the problem? Addressing the energy paradox of the circular economy

Eficiência, qual é o "watt" do problema? Enfrentando o paradoxo energético da economia circular

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Abstract

This paper explores the integration of the Circular Economy within the energy sector, focusing on the European Union's legislative and policy context. It examines the evolution and definitions of the Circular Economy, highlighting its expansion from waste management to a broader sustainability paradigm. The analysis uses a comparative approach between the theoretical definition of the circular economy and energy efficiency. It emphasizes the biophysical and thermodynamic limits of circularity, particularly the impossibility of creating closed energy loops due to the laws of thermodynamics. The role of energy efficiency emerges as a crucial bridge between circularity and sustainability, with the EU's "energy efficiency first"

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principle serving as a key policy tool. The study argues that while material loops can be narrowed, energy flows remain inherently linear, making efficiency measures essential for advancing circular objectives. The relationship between energy efficiency and the Circular Economy is presented as mutually beneficial but asymmetrical, with efficiency being indispensable for circularity's success.

Keywords: Circular economy; energy efficiency; energy law; sustainability; thermodynamics.

Resumo

Este artigo explora a integração da Economia Circular no setor de energia, com foco no contexto legislativo e político da União Europeia. Examina a evolução e as definições da Economia Circular, destacando sua expansão da gestão de resíduos para um paradigma de sustentabilidade mais amplo. A análise utiliza uma abordagem comparativa entre a definição teórica da economia circular e a eficiência energética. Enfatiza os limites biofísicos e termodinâmicos da circularidade, particularmente a impossibilidade de criar ciclos fechados de energia devido às leis da termodinâmica. O papel da eficiência energética surge como uma ponte crucial entre circularidade e sustentabilidade, com o princípio "a eficiência energética em primeiro lugar" da UE servindo como uma ferramenta política chave. O estudo argumenta que, embora seja possível estreitar ciclos materiais, os fluxos de energia permanecem inerentemente lineares, tornando medidas de eficiência essenciais para promover os objetivos circulares. A relação entre eficiência energética e Economia Circular é apresentada como mutuamente benéfica, mas assimétrica, sendo a eficiência indispensável para o sucesso da circularidade.

Palavras-chave: *Economia circular; eficiência energética; direito da energia; sustentabilidade; termodinâmica.*

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1. Introduction

The circular economy has become an essential element of the strategy of the European Union to create a decarbonised economy (European Commission, 2015). It is expected that the implementation of the circular economy will allow growth to be decoupled from resource use, which will enable the preservation of natural resources and progress towards sustainability (European Commission, 2015). Despite initially being confined to the waste-management sector (Lazarevic; Brandão, 2023, pp. 19–21), the concept of the circular economy was expanded so as to encompass a wide array of policy domains. In recent years, it has, notably, come to play a prominent role in the green transition and thus in the energy sector. However, this expansion may have placed the circular economy in a precarious position. This paper aims to offer a theoretical explanation of the role of the circular economy in energy law, and it links the two via the concept of energy efficiency. The objective is to provide a theoretical approach towards the circular economy bridging the biophysical limits to the circular economy, which shape theory and practice alike. The focus of this paper is to provide lawyers with a technical and theoretical understanding of the circular economy which will facilitate the application of the circular economy beyond waste management, specially into areas that include energy.

The theoretical analysis is framed by reference to the European Union due to its commitments to the circular economy, the green transition and net zero by 2050. These commitments have produced legislation in energy and circular economy areas that can be analysed to see the application of the circular economy for the objectives of decarbonisation of energy supply.

The paper is structured as follows: the first section explores the concept of a circular economy and the link between circularity and sustainability. In Section 2, the limitations of the circular economy are established according to the principles of thermodynamics. Section 3 further focuses on the role of energy in the circular economy. In Section 4, the concept of energy efficiency and the energy-efficiency-first (EE1) principle are introduced as means of bridging the gap between energy and the circular economy.

2. The Idea of a Circular Economy

It is difficult to even begin describing the circular economy: its definitions differ as widely as its implications. The uncertainty that results from the incongruous definitions of the concept endangers its transformative potential (Kirchherr, 2017, p. 229). Its semiotic core is in its own semantics (Murray; Skene; Haynes, 2017, p. 375–377): the circular economy is unlike the linear one in that products are expected to have an afterlife of reuse and recycling, whereas under the conventional paradigm production, consumption and disposal are all mapped onto a straight line.

The current concept of the circular economy first emerged in 1990 with the publication of Peace and Turner's *Economics of Natural Resources and the Environment* (Pearce; Turner, 1990). The two authors are credited with coining the term "circular economy". The concept was strongly influenced by the development of the field of environmental economics in the 1960s and 1970s (Alexander, 2023, pp. 19-20). "The Economics of the Coming Spaceship Earth" (Boulding, 1966) is usually cited as one of the starting points of the circular-economy idea as it is conceived at present (Kovacic; Strand; Völker, 2020, pp. 14–20).

Despite the concept having developed over the last 30–50 years (Murray; Skene; Haynes, 2017, pp. 371–374), the idea of keeping products in use and reducing waste as much as possible is far from new. Several authors have traced its roots back to the economic theories of the eighteenth century (Lazarevic; Brandão, 2023, p.13). Malthusian economics have also shaped the foundations of the circular economy (Kovacic; Strand; Völker, 2020, pp. 15–17; Lazarevic; Brandão, 2023, pp. 12–14). Recycling and repurposing have been crucial for the economies of almost all human societies, from the dawn of man to complex civilisations such as ancient Egypt, Rome and China (Bavuso et al., 2021). Until recent times, the disposal of a product without repurposing it was the preserve of an elite that produced conspicuous waste (Watkins, 2019), and a modern person would be surprised at the commonality of reutilisation until the 1950s (Kosir, 2023, p. 87).

Today, the circular economy is one of several buzzwords that must seemingly adorn every policy paper and recommendation (Lazarevic; Brandão, 2023, pp. 19, 23). The fuzziness of the concept is an added advantage for the legislator (Mellado Ruiz, 2023, p. 23) because the resultant broad margin of interpretation can dilute concrete actions into vague promises (Kovacic; Strand; Völker, 2020, pp. 46–47). Murray thus observed that the circular economy appears to have originated not from academic writing but from legislation, specifically from Japanese and German policies from the eighties and nineties (Murray; Skene; Haynes, 2017, pp. 371–372). The influence which the circular economy has exerted on Chinese development is likewise palpable (Geng et al., 2012), and the concept of circularity appears to drive the policy agenda (Lazarevic; Brandão, 2023, pp.19–20).

Many stakeholders, including governments and NGOs, as well as academics, have defined the circular economy; each definition has different implications. Here, I will review some of the more influential ones. The EU is a leading governmental actor, and it has included the principles of the circular economy among its priorities. The foundational document in this regard is the Action Plan for the Circular Economy of 2015. This Plan introduced the EU definition of the circular economy: an economic system in which the value of products, materials and resources is maintained in the economy for as long as possible and the generation of waste is minimised (European Commission, 2015). This approach is broad enough to be extensible to a wide range of policies and tepid enough to skirt most firm commitments (Lazarevic; Brandão, 2023, pp. 13-15). It is also important to note that the circular economy is said to be “an essential contributor (…) for sustainable, low carbon, resource efficient and competitive economy” (European Commission, 2015).

The Green Deal of 2019[1] made the circular economy more necessary without, however, making any direct references to that concept. The aim of the Green Deal is to

> transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use (European Commission, 2019).

It seems fairly clear that the decoupling of growth from resource use will, at the very least, require a recalibration towards circularity.

The Green Deal also includes the objective of “*mobilising industry for a clean and circular economy*” (European Commission, 2019), which clearly adverts to circularity. Sectors such as steel and chemicals are considered strategic EU industries; due to their energy intensity, they should be the frontrunners of circularity and decarbonisation. Further measures to achieve this goal will be implemented through the EU Industrial Strategy[2] and the new Circular Economy

[1] EU flagship policy framework aiming for climate neutrality by 2050. It sets overarching objectives—zero net greenhouse-gas emissions, decoupling economic growth from resource use, and fostering a fair, resource-efficient economy—it serves as the political umbrella for subsequent sectoral strategies, including the Circular Economy Action Plan and Clean Industrial Deal.

[2] The strategy from March 2021 guides the transformation of key energy-intensive sectors (steel, chemicals, cement) toward sustainability and digitalisation, reinforcing their competitiveness. It integrates circular-economy principles by incentivising low-carbon production, resource efficiency, and strategic value-chain resilience.

Action Plan from 2020[3]. That Plan lacks a definition of the circular economy because the Commission focuses on specific activities, such as design, production and consumption, or on specific sectors, such as plastics, waste or chemicals (European Commission, 2020). The definition from 2015 is retained as the foundation for the Circular Economy Actions of the EU. That the legislator often cites the principle but has never defined it clearly is widely acknowledged to be problematic.

The last impulse for the circular economy in the EU came from the Clean Industrial Deal[4], in which circularity was cast as a priority, and the EU indicated that it was aiming to be at the forefront of its implementation (European Commission, 2023). Circularity is viewed as:

> The key to maximising the EU's limited resources, reducing dependencies and enhancing resilience. It reduces waste, lowers production costs, lowers CO2 emissions and creates a more sustainable industrial model that benefits the environment and enhances economic competitiveness (European Commission, 2023).

The goals of the Clean Industrial Deal are meant to be achieved through a new Circular Economy Act, which should appear in 2026, and by reinforcing the commitments from the EU Critical Raw Materials Act[5]. Some authors have argued that the EU views the circular economy as a means rather than as an end: the goal is decarbonisation rather than circularity (Kovacic; Strand; Völker, 2020, pp. 38-45).

The UNECE has adopted a different definition of the circular economy as:

> A new and inclusive economic paradigm that aims to minimise pollution and waste, extend product lifecycles and enable the broad sharing of physical and natural assets. That economy is competitive but also creates green and decent jobs and restricts resource use by reference to the planetary boundaries (UNECE, 2023).

Another relevant NGO definition is that of the Ellen McArthur Foundation, which is usually quoted as the leading institution on the promotion of the circular economy (Lazarevic; Brandão, 2023, pp. 10–11); the EU also refers to it in the two Circular Economy Action Plans. The current definition that the Ellen McArthur Foundation employs runs thus:

> The circular economy is a system in which materials never become waste and Nature is regenerated; in a circular economy, products and materials are kept in circulation through processes such as maintenance, reuse, refurbishment, remanufacture, recycling and composting; the circular economy tackles climate change and other global challenges, such as biodiversity loss, waste and pollution, by decoupling economic activity from the consumption of finite resources. (Ellen MacArthur Foundation, 2022).

Evidently, the Ellen McArthur Foundation definition of the circular economy is not only longer than the one which the Commission uses but also much more ambitious and complex. One of the several notable differences is that the EU focuses on reducing waste while the Ellen McArthur Foundation aims at its eradication. Combatting climate change and other challenges forms part of the Ellen McArthur definition, too. The EU definition, conversely, is much easier to implement.

Definitions of the circular economy have also been essayed in academia. Murray has proposed defining the circular economy as:

[3] This Plan develops the Green Deal compromises by identifying priority value chains (e.g., plastics, batteries, textiles) and sets measures—ecodesign, reparability targets, waste-stream standards—to keep materials in use longer, minimize waste, and reduce resource dependency

[4] It aims to translate the Green Deal ambitions into a roadmap for decarbonizing energy-intensive industries. It introduces the Industrial Decarbonisation Accelerator, promoting breakthrough technologies (e.g., green hydrogen, carbon capture) and integrating circularity criteria alongside cost when funding large-scale projects

[5] Adopted in March 2023, establishes EU benchmarks to secure supply chains for 34 critical raw materials by 2030, requiring at least 10% of consumption to be sourced within the EU, 40% processed domestically, and 15% recycled it an improved end-of-life recovery rates, thereby embedding circular-economy principles into the EU's raw-materials policy.

> An economic model in which planning, resourcing, procurement, production and reprocessing are designed and managed, both as processes and outputs, so as to maximise ecosystem functioning and human well-being’ (Murray; Skene; Haynes, 2017, p. 377).

Geissdoerfer defines the circular economy as:

> A regenerative system in which resource inputs, waste, emissions and energy leakages are minimised by slowing, closing and narrowing material and energy loops. These objectives can be attained through long-lasting designs, maintenance, repair, reuse, remanufacturing, refurbishing and recycling (Geissdoerfer et al., 2017, p. 766).

Kirchherr defines the circular economy as follows:

> It is as an economic system that replaces the end-of-life concept with reductions, reuse, recycling and recovery in production, distribution and consumption processes. It operates at the micro level (products, companies and consumers), at the meso level (eco-industrial parks) and at the macro level (the city, the region, the nation and beyond), with the aim of achieving sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity for the benefit of current and future generations. The circular economy is enabled by novel business models and responsible consumers (Kirchherr, 2017, p. 229).

The small differences between these definitions can have large implications for the implementation of the concept. This should not be taken to imply that all problems with the circular economy are definitional – natural laws also impose important constraints on its rollout. Two of the main implications are the role of energy in the circular economy that is explored trough this paper and it will be further addressed in section 2 and the intersection between sustainability and circularity. But other elements of the definition can also impact the approach towards circularity. Not only how the EU definition is formulated broad enough to ease its application (Kovacic; Strand; Völker, 2020, pp. 38-45). Kirchherr definition is by far the most ambitious of the ones presented as it stretches in a multilevel framework including all social actors and it also stretches the social benefits further including not only environmental protection but also equity and prosperity. In comparison Murray definition does not present such clear goals as it only aims for an optimal *ecosystem functioning and human well-being,* opening then the question of what constitutes optimal human well-being and for example does this well-being include equity such as in Kirchherr or is this possible without it. In contrast Geissdoerfer does not mention any social issues as it solely relies on material analysis and nature restoration. The inclusion of social issues can also be seen in institutional definitions; it is present on the UNECE but absent from the EU approach.

Energy and material loops can in theory be narrowed by recurring to contested labour and social practices, as it current happens on several recycling processes in the global south, even further it could be argued that such cheap labour could allow for a circular economy that fits Geissdoerfer definition. This leads to the following question, how much should the circular economy aim for. The circular economy does not occur in a legislative vacuum. We have indeed labour and human rights regulations that would prevent a slave labour powered circular economy. Should the definition of the circular economy aim at being a panacea or should its definition just be tailored to its domain and focus on the avoidance of waste and squandering of resources.

Most of definitions examined contain some mention to the environmental protection. Either to regeneration of nature or towards sustainability. Sustainability and circularity are similar on multiple dimensions. The main difference between the two are that they have different end goals. The circular economy clearly aims at the creation of a loop, whereas sustainability is much more diffuse, and it revolves around the idea of a system that can maintain itself or of giving Nature time to regenerate Another crucial difference has to do with beneficiaries. The main beneficiary of sustainability is the environment; the main beneficiary of the circular economy is the economy. One of the main advantages of the circular economy is that its application is simpler than for sustainability because its implementation lies in the hands of the legislator and private businesses (Geissdoerfer *et al*., 2017, pp.759-758, 764-766).

Three main strands of the literature describe the relationship between the circular economy and sustainability; they are premised on the ideas of conditionality, benefit, and trade-offs (Geissdoerfer et al., 2017, p. 766). The EU and the UN see the relationship in question as beneficial. Some academics describe it as conditional, in that it would not be possible to establish a circular system without decreasing the consumption of resources (Mellado Ruiz, 2022, p. 31), but a decrease in consumption of resources alone would not cause the entire economy to become sustainable. As will be explained in next section, non-renewable resources, such as minerals, cannot be used sustainably because they are doomed to be dispersed and to disappear (Kovacic, 2020, p. 71). Biophysical cycles are long – the regeneration of resources such as phosphorus or nitrogen can take as long as 2,000 years (Murray et al., 2017, p. 371). A circular system is not linked to the regeneration of Nature, which would be required for full sustainability to obtain. Thus, circularity will not deliver sustainability in the biophysical sense of that term; its potential to reduce the rate of consumption is an altogether separate matter (Kovacic, 2020, pp. 74–75).

Biophysical constraints and the unpredictable link between economics and Nature have caused several authors to doubt that circularity will deliver sustainability (Schoder *et al*., 2019; Korhonen; Honkasalo; Seppälä, 2018, p. 43). Some authors go as far as to question whether the increase in circulation and the reduction in the extraction of virgin materials could create unsustainability in the long term due wto the unknown effects of changes to economic structures that they will induce (Korhonen; Honkasalo; Seppälä, 2018, p. 43). However, even if circularity does not allow for full sustainability, it does allow for more sustainability, and thus for the possibility of postponing economic collapse (Millar *et al*., 2019, p. 15).

The relationship between sustainability and the circular economy should not be confused with the much broader relationship between the circular economy and sustainable devolvement, which is also the subject of a voluminous literature. The notion of sustainable development includes economic and social issues as well as environmental ones (Korhonen; Honkasalo; Seppälä, 2018, p. 547). Another issue that is further pass sustainability is the idea of the circular economy being regenerative by design (Geissdoerfer *et al*., 2017, p. 766). A regenerative system does not simply aim at the maintenance of a natural ecosystem, but it seeks to actively repair the harm that it has been previously caused to it (Raworth, 2023, pp. 49-56), which in fact would increase the ambition of a Circular economy system.

3. Entropy and Thermodynamics, the Natural Limits of the Circular Economy

The circular economy has several limitations. Some are social and legal, others are physical (Korhonen; Honkasalo; Seppälä, 2018, pp. 41–45). Georgescu-Roegen identified the physical limits to the circular economy as early as the 1970s (Georgescu-Roegen, 1971). Even before that time, Boulding discussed how energy limits the idea of material loops in his highly influential “The Economics of the Coming Spaceship Earth[6]” (Boulding, 1966).

According to the first law of thermodynamics, energy is neither created nor destroyed – it is merely transformed (Schneider; Sagan, 2005, pp. 26-27). Therefore, energy cannot be retained in an endless cycle. The production and use of energy are more linear than they are circular: energy can cascade to lower levels, but it is not reused because it is subject to an inexorable process of dissipation (Schneider; Sagan, 2005, pp. 25-30).

The first law of thermodynamics thus implies that energy cannot be created or destroyed, only transformed. However, according to the second law of thermodynamics, not all heat can be converted into work cyclically (Schneider; Sagan, 2005, pp. 6-8, 26-28). Therefore, no matter how circular a system is, it will never be fully efficient – there will always be losses in material and quality. In addition, fresh energy outputs are needed to sustain the recycling process (Lazarevic; Brandão, 2023, pp. 11–13). Boulding remarked that only materials can form a closed circle and that a new energy input is always necessary (Boulding, 1966, pp. 2–3).

[6] A model in which Earth is featured as a closed system for materials but an open one for energy, underscoring the necessity of external energy inputs for sustaining closed material loops.

According to the second law of thermodynamics, entropy increases in closed systems. Heat flows from hot to cold objects. The implication of the second law of thermodynamics is that a system requires an input of energy to maintain its order (Schneider; Sagan, 2005, pp. 6-10, 26–32). This energy input comes in different shapes and sizes, from the Sun and the wind to fossil fuels. Every civilisation has made use of different sources of energy to evolve – the Stone Age had fire, and we have nuclear reactors. Not even human life can be sustained without energy inputs (Schneider; Sagan, 2005, pp. 68-71, 261–265).

Here, it is also important to determine what a closed system is. Boulding considered the Earth to be one such system. Nevertheless, the Earth has external energy flows, chiefly in the form of solar energy. Georgescu-Roegen wrote that while solar energy technology might be technically “feasible”, it cannot be “viable” because it is never possible to construct all of the necessary infrastructure by only using solar energy (Ayres, 1999).

Furthermore, there is the problem of material degradation. The possibility of endless recycling has been debated in environmental economics. Georgescu-Roegen speculated that there is always entropic loss, irrespective of the recycling process; therefore, total material depletion is inevitable in the long run (Georgescu-Roegen, 1979). Daly also subscribed to the view that full material recycling is impossible (Daly, 1992, pp. 91–92). Ayres maintained that there is no material loss, only dissipation, and that the only limit is the need for new energy (Ayres, 1999, pp. 474–480). With an infinite energy supply, all waste could be subjected to material recovery, and no raw material would be lost. The only remaining obstacle would be the space that is needed for the storage of waste and its potential environmental impact (Ayres, 1999). Valero and Valero wrote that the current circular mode only allows for first-material recycling, and the further recycling of recycled materials is neglected in contemporary theory and practice. The circular economy which they proposed is instead based on spirals that account for material degradation after each recycling cycle (Valero; Valero, 2014, pp. 79–108). At the end of the spiral, there is the doom of Thanatia[7], an Earth that is filled with unusable materials (Valero; Valero, 2014, pp. 211–217).

Nothing is eternal, not even renewable energy. The Sun will one day deplete its energy sources and turn into a white dwarf, and thus the "free" supply of energy to Earth will cease. Materials will also dissipate and deplete through the operation of several processes. However, the depletion of our stock of materials is likely to take longer than the depletion of our reserves of fossil fuel (Boulding, 1966, p. 4). As things stand, it is more likely that we will run out of the energy that we need for recycling than that we will run out of things to recycle.

Obviously, although it cannot be maintained in perpetuity, the circular economy should run for as long as possible (Boulding, 1966, p. 5). A sufficient external supply of energy determines the feasibility of a closed material economy (Ayres, 1999). Energy will never be fully circular, and an external supply will always be needed. In this model, solar and other renewable energy sources function as *dei ex machina*. This state of affairs leaves two questions open. The first has to do with continuous reliance on technological advancements, and the second has to do with the need for scarce materials to build the infrastructure for the production of the required renewable energy (Valero; Valero, 2014, pp. 16-21). Even in a Thanatia scenario in which material and fossil-energy stocks are depleted (Valero; Valero, 2014, pp. 16–21), the Sun will still shine over the wasteland – it is only (material) capacity for using this renewable energy that will be lacking.

Jevons believed that there is no source of energy that can substitute coal (Georgescu-Roegen, 1971, p. 295). Georgescu-Roegen argued that all the sources of energy would eventually be depleted (Georgescu-Roegen, 1971, pp. 296–298). Conversely, Boulding viewed the Sun as a constant and unlimited source of energy (Kovacic; Strand; Völker, 2020). He called fossil fuels “stored-up sunshine” which provides a limited supply (Boulding, 1966, p. 2). In his view, while the use of the reserves in question has allowed the economy to develop, that they are depletable means that future growth should rely on other infinite sources, such as the Sun, and he even suggested biofuels that were based on an early stage of anaerobic digestion through algae (Boulding, 1966, p. 4). When Boulding wrote, it was unclear

[7] A theoretical end-state in which spiral recycling reaches a final accumulation of degraded, unusable materials, illustrating the limits of infinite loop models.

whether society would be able to function without fossil fuels and if their disappearance would result in the involution of the economy. The development of renewable energy over the last 60 years has generated a more optimistic view of a future without fossil fuels. This development also opens the door for further innovations in the supply of energy.

4. The Role of Energy in the Circular Economy

Now that I have described the natural limits to the circular economy, I turn to their legal and theoretical analysis. The definitions that were examined in the first section revolve chiefly around waste minimisation and extending the life of products through recycling and repurposing. However, there is one critical element that is mostly ignored, namely energy. Processes such as recycling, repurposing or repairing need energy inputs. Only Geissdoerfer mentions energy when defining the circular economy, stressing the importance of minimal leakage and narrow loops (Geissdoerfer et al., 2017, p. 766). Narrow energy loops are also mentioned by Prieto-Sandoval, Jaca and Ormazabal, who believe that the role of energy within the circular economy is to close material and energy loops in order to make intensive use of the resources that are at our disposal instead of increasing exploitation and environmental harms (Prieto-Sandoval; Jaca; Ormazabal, 2018). These energy loops should be linked to the functioning of a circular system. A closed-loop system (Bocken, 2016, p. 309) can be a loop of production, consumption and recycling, whereby a closed loop means that there is no waste (or that it is minimised as much as possible within the process) so that the resources can be used repeatedly (Stahel, 2010, pp. 192–195; Ritala; Bocken; Konietzko, 2021, p. 178). The closed loop can also be one of consumption and reuse, whereby recycling is unnecessary because products are used continuously (Stahel, 2010, pp. 192–195; Bocken, 2016, p. 309).

Glass bottles supply a salient example. Common glass, such as that which is found in bottles for wine and water, is composed of silica sands, sodium carbonate and calcium carbonate. Those substances are heated at temperatures in excess of 1500 °C for around 24 hours, which yields molten glass that can be worked into a final product. A glass bottle can be cleaned and refilled around 15 times before it has to be recycled (Zero Waste Europe, 2020). Once the glass has reached the end of its life, it can be ground and remelted to produce molten glass. While the process can be repeated without new raw materials, furnaces still need to be heated repeatedly, and that heat cannot be reused. Current glass furnaces run on electricity, gas or oil. Nevertheless, there are some material limitations chiefly due to contamination between different types of glass or with other materials, therefore challenging the endlessness of the recycling process. (Barbato, 2024, Zero Waste Europe, 2020).

Similarly recycling of metals such as aluminium or steel require an input of energy to melt and rework the material but face more significant challenges. In steel copper contamination of the scrap metal significantly reduces the recyclability of the material (OECD, 2021, pp. 13-19). While in aluminium the material degradation arises from oxidation during the remelting process and increased impurities make aluminium unsuitable for certain uses such as aerospace components (European Aluminium, 2022). While material degradation is indeed a limit and a future risk for the Circular Economy it is a phenomenon that occurs at a smaller rate than the unavoidable need for (new) energy inputs. In fact higher energy inputs are able to curb or reduce material degradation for example via higher temperate electrochemical purification of steel to reduce its copper impurities (Paeng, 2024) or electrowinning to reduce losses in aluminium recycling (International Aluminium Institute, 2024). This demonstrates the importance of energy as a component of the circular economy.

While in principle, a material loop can be closed, but an energy loop cannot because new energy inputs are needed each time. A reuse-based closed loop requires less energy than a recycling-based one (Stahel, 2010, pp. 193–194), but, in both cases, the closed loop still needs energy and thus runs into the thermodynamic limits that were described previously. Some have ventilated the idea that an energy loop can be closed by developing a renewable energy supply (Zell-Ziegler, 2021, p. 2). However, the closing of the energy loop is a fallacy akin to that of perpetual movement – a new energy input is always necessary.

What are narrow loops in practice? A narrow loop is thought to be less resource intensive due to gains in the efficiency of various processes (Ritala; Bocken; Konietzko, 2021, p. 178). However, the narrowing of loops only results in improved efficiency, not in an overall decrease in consumption (Bocken, 2016, pp. 310-311). The Jevons Paradox[8] bites: higher efficiency drives prices down, leading to higher demand (Martinez Alier, 2015). The Jevons Paradox was originally observed in the energy context: the consumption of coal would increase because of improvements in the efficiency of James Watt's steam machine (Jevons, 1865, pp. 204–219).

While new energy will always be needed, it is possible to apply at least some circular economy measures to energy, specifically energy recovery and waste-to-energy (Reike; Vermeulen; Witjes, 2018, pp. 256–257). These measures allow energy that would otherwise be lost to be recovered or materials that would otherwise go to waste to be repurposed into energy (Reike; Vermeulen; Witjes, 2018, pp. 256–257); once again, when this energy is used, it dissipates, in line with the laws of thermodynamics (Daly, 2019). Even if some energy can be recovered, it eventually fades away (Schneider; Sagan, 2005, pp. 26–32).

Even when energy is present in the theories of the circular economy, it appears as a loop that should be narrowed; however, no indication of the provenance of the energy is given. The energy in the loop can be either from fossil sources or from renewable ones. In this regard, the Ellen McArthur Foundation writes as follows:

> [i]ncreasingly built on renewables, and the endless flow of energy from the sun (energy in surplus), a Circular Economy is one which transforms materials into useful goods and services (Ellen MacArthur Foundation, 2022).

Energy is also one of the main concerns of the advocates of the cradle-to-cradle paradigm[9], which casts fossil resources as emergency reserves (McDonough; Braungart, 2002, p. 32) and posits that renewable energy should power a new economic paradigm (McDonough; Braungart, 2002, pp. 4–5, 32, 136–140). Alternative visions of the circular economy also rely on renewable fuels and arguments to displace fossil fuels (Cowie, 2019, pp. 385, 390–393).

5. Efficiency and Circularity, From Efficiency to Energy Efficiency first principle

The current concept of energy efficiency emerged during the 1970s as a response to the oil crisis, and it is directed at reducing consumption so as to enhance the security of the energy supply (Roggenkamp, 2023). The development of alternative sources of energy was seen as a counterpart to these measures. The current definition which the EU gives in its Energy Efficiency Directive ties efficiency to the ratio of outputs of performance, service, goods or energy to inputs of energy (European Parliament and Council, 2012, Art. 2(4)).

Despite seeming to be widely accepted, efficiency also has conceptual drawbacks. As noted previously, the Jevons Paradox implies that sustainability cannot be achieved solely through gains in efficiency (Darby, 2007, p. 114). Another problem with efficiency has to do with the role of technology (Zell-Ziegler et al., 2021, p. 3) – similarly to circularity, efficiency relies on constant successful innovation (Rosenov; Kern, 2017, pp. 512-514) to decrease consumption.

The idea of sufficiency has been developed as a corollary to energy efficiency (Darby, 2007; Zell-Ziegler et al., 2021, pp. 2–3). Its definition is also contested, Zell-Ziegler defined energy sufficiency as the strategy of achieving absolute reductions in the amount of energy-based services that are consumed, notably through the promotion of intrinsically low-energy activities, so as to reach a level of sufficiency that ensures sustainability (Zell-Ziegler et al., 2021, pp. 2–3). The main

[8] Developed in 1865 by the Economist William Stanley Jevons, it postulates that increases in resource-use efficiency—such as a more fuel-efficient steam engine—can lower costs and thus stimulate greater overall consumption.

[9] A design philosophy introduced by McDonough and Braungart advocating that products be conceived from the outset for perpetual material circulation and powered by renewable energy. Unlike traditional circular models focused on narrowing loops, cradle-to-cradle emphasises fully regenerative systems in both materials and energy.

benefit of sufficiency is that it responds to the Jevons Paradox by advocating for direct reductions in consumption. The structural risk is that sufficiency has a very strong moral dimension (Darby, 2007, pp. 111–112, 115).

The EU legislator has developed energy efficiency in multiple legal instruments, and the scope of the concept has been expanded to include the production and consumption of energy as well as maters such as the performance of appliances and budlings. The Energy Efficiency Directive of 2012 (Roggenkamp, 2023, p. 747) includes efficient energy production through cogeneration, that is, through the repurposing of the heat which is dissipated during the production of electricity (Roggenkamp, 2023 p. 747). The Directive also includes targets for energy efficiency for the Member States (Roggenkamp, 2023, pp. 747–748), which include, for example, the obligation to provide clear consumption data to consumers (Roggenkamp, 2023 p. 747). In this case, efficiency is perceived as a tool in the pursuit of decarbonisation.

In 2015, the Framework Strategy for a Resilient Energy Union introduced the idea of the savings from energy efficiency as a distinct source of energy (European Commission, 2015, 2.3). The EU commitment to energy efficiency eventually crystallised into the EE1 principle, which was introduced in 2018 through the Governance Regulation (European Parliament and Council, 2018, Recital 64, Art. 2.18). EE1 is defined as follows:

> Energy efficiency first" means taking utmost account in energy planning, and in policy and investment decisions, of alternative cost-efficient energy efficiency measures to make energy demand and energy supply more efficient, in particular by means of cost-effective end-use energy savings, demand response initiatives and more efficient conversion, transmission and distribution of energy, whilst still achieving the objectives of those decisions (European Parliament and Council, 2018, Art. 2).

The Energy Efficiency Directive of 2018 was amended at the same time as the Governance Regulation to promote the implementation of the principle (European Parliament and Council, 2018, Art. 1). Further development resulted from the revision of the Energy Efficiency Directive in 2023. Article 3 of the Directive enshrines EE1 as a principle by requiring that energy-efficiency solutions be considered in planning, policy and investment decisions, both in the energy section and beyond, for example in transport-infrastructure projects. Article 3.5 states that it is mandatory to promote and, where cost-benefit analyses are required, ensure the application and publication of cost-benefit methodologies that allow for a proper assessment of the wider benefits of energy-efficiency solutions. The matters that these methodologies ought to take into account include the entire lifecycle of the solution, its long-term outlook, its system and cost efficiency, the security of the energy supply, and quantifiable societal, sanitary, economic and climate-neutrality costs and benefits, as well as the sustainability and circular-economy principles that govern the transition to climate neutrality (European Parliament and Council, 2023, Art. 3).

The EE1 principle has outgrown the concept of efficiency (Yu, Mandel and Brugger, 2022), in that it stands for more than just the idea of turning demand-side management into a source of energy (European Commission, 2015, 2.3). Efficiency is preferred, and savings are prioritised (Chlechowitz, 2021). As a principle, EE1 should apply to all energy planning, policy and investment decisions so as to optimise the energy system (Chlechowitz, 2021; European Parliament; Council, 2018).

In the 2023 version of the Energy Efficiency Directive, the Commission linked energy efficiency to the circular economy. The link is not entirely clear because the circular economy appears as one of several criteria that can be considered when evaluating the eventual benefits of the application of EE1 – assessments of the potential costs of a measure from an EE1 perspective should account for effects such as circularity rather than focusing exclusively on financial cost. The application of the EE1 principle fosters decisions that are very much in line with the circular economy, for example by promoting the utilisation of existing gas infrastructure as part of the planned hydrogen network (Jimenez Casanova; Pinto, 2022, pp. 287–288). Accordingly, EE1 allows for a superior implementation of the circular-economy principles: the pursuit of circularity result in higher initial costs becoming more acceptable (Kirchherr et al., 2017, pp. 226–228) due to the promise of lower material consumption. This consideration of non-financial costs is also in evidence in the Clean Industrial Act, where circularity and sustainability criteria were added through the Industrial Decarbonisation

Accelerator Act as elements to be consider along with the cost when providing clean energy to intensive industrial users (European Commission, 2023, 3.1). Other criteria can be considered as well, but while the aim is to reduce energy consumption, there is no direct recourse to the notion of efficiency (European Commission, 2023, 3.1).

6. Discussion

According to the rules of thermodynamics, energy cannot be retained in a loop, but this does not mean that the circular economy should ignore energy. In fact, the pursuit of a circular economy is constrained by demand for energy to power the diverse processes which repurposing, recycling and the like entail. An intrinsically linear flow should be transformed into a model that targets the creation of loops. The proposed theoretical adaptations to the problem of looping a line include narrowing, that is, decreasing consumption, and making more rational use of the energy resources which cannot be looped. This narrowing of the loop dovetails into the concept of energy efficiency. However, discussions of the circular economy have previously neglected energy efficiency and have instead focused on the use of materials; when it is not disregarded, energy is subjected to a perfunctory analysis that is limited to pointing either at the necessity of using renewables or at that of forming narrow energy loops. While renewable energy sources are the only future-proof source to supply the continuous energy inputs required by recycling processes they should not be treated as “free lunch”. The production of the required infrastructure such as solar panels or batteries entails significant material, energy and financial costs. It should be stressed that renewable energy is the only possible source for a circular economic model but not alone, the energy should be used in the most rational and efficient way as possible due to the impossibility of creating a closed energy loop.

The EU has started to move towards this direction in its most recent legal developments that have seen energy efficiency become the EE1 principle: circularity can now justify higher upfront costs for projects. It should be noted that, while this relationship is mutually beneficial, it is also unequal. Energy efficiency can be understood and applied without circularity. Industrial processes can be made more efficient, and leakage can be minimised. Such a development would decrease energy consumption and, according to the laws of neoclassical economics, contribute to decreases in price and thus to increases in demand. The Jevons Paradox is sure to manifest in these circumstances. Conversely, a circular economy targets waste minimisation and reductions in the consumption of raw materials. The consumption of energy should also be reduced by higher energy efficiency. However, the limit to the influx of new materials into the economic flow should circumscribe the impact of the Jevons Paradox because higher demand would not be met due to a scarcer supply.

The relationship between the circular economy and energy has much broader implications, too. It is not just circular benefits that should be considered – the circular model should advance energy efficiency because it is the only possible means of minimising the impact of unavoidable energy needs. Only if energy efficiency is applied within a circular system will it be possible to minimise the effect of the Jevons Paradox because the gains in efficiency would then be delimited by a loop. Recycling processes consume less energy than the extraction of virgin raw materials, even if sometimes they face higher upfront costs. The application of the EE1 principle as part of circularity would allow to frame it as a planetary entropy management tool that would allow to bypass the initially higher costs to promote renewable and more efficient energy technologies as part of the circular economy. The regulator should take it into account to provide regulation that is not only in line with the reduction of waste and material use but that it also makes an efficient use of energy for the production, recovery and recycling processes.

7. Conclusion

It remains exceedingly difficult to define the circular economy exactly. Nevertheless, its goals are clear, especially for the EU, which has made several commitments to the implementation of such an economy. At the same time, the Union is also committed to energy efficiency, and it treats the resultant savings as an autonomous source of energy. Due to biophysical limitations, the only way to fit energy into the circular economy is via efficiency. The EE1 principle can benefit circularity and should be employed accordingly. At the same time, since energy is needed for all transformative processes, energy efficiency should be subsumed into the circular economy because the latter cannot be achieved without the former.

From a legal perspective, the alignment of circularity and energy efficiency signals a shift for policymakers. Energy savings are not a mere extra source of energy but fundamental to achieving circular-economy targets. Future regulations should incorporate quantitative entropy management metrics, rewarding projects that maximize material value while minimizing energy dissipation. In addition to the broader considerations included inside the EE1 principle.

References

ALENZA GARCÍA, José Francisco. La dimensión jurídica del paradigma de la economía circular: aportaciones legislativas y jurisprudenciales. In: GUAYO CASTIELLA, Íñigo del; MELLADO RUIZ, Lorenzo (dirs.). **Retos regulatorios de los gases renovables en la economía circular**. Madrid: Marcial Pons, 2023. p. 19-35. 2023.

ALEXANDER, Catherine; PASCUCCI, Stefano; CHARNLEY, Ben (eds.). **Handbook of the Circular Economy**. Berlin: De Gruyter, 2023.

AYRES, Robert U. The second law, the fourth law, recycling and limits to growth. **Ecological Economics**, v. 29, n. 3, p. 473-483, 1999.

BARBATO, Paolo Matteo. Quality degradation in glass recycling: substitutability model for waste management systems. **Waste Management**, v. 178, p. 113-124, 2024.

BAVUSO, Silvia et al. Circular Economy in the Roman Period and the Early Middle Ages - Methods of Analysis for a Future Agenda. **Open Archaelogy**, v. 9, n.1, 2023.

BOCKEN, Nancy M. P. **Product design and business model strategies for a circular economy**. **Journal of Industrial and Production Engineering**, v. 33, n. 5, p. 308-320, 2016.

BOULDING, Kenneth Ewart. The Economics of the Coming Spaceship Earth. In: JARRETT, Henry (ed.). **Environmental Quality in a Growing Economy**. Baltimore: Johns Hopkins University Press, 1966. p. 3-14.

CHLECHOWITZ, Malte. How first comes energy efficiency? Assessing the energy efficiency first principle in the EU using a comprehensive indicator-based approach. **Energy Efficiency**, v.15, n.59.

COWIE, Annette L. Bioenergy in the circular economy. In: BRANDÃO, Miguel; LAZAREVIC, David; FINNVEDEN, Göran (eds.). **Handbook of the circular economy**. Cheltenham, Edward Elgar, 2020. p. 382-395.

DALY, Herman E. Is the entropy law relevant to the economics of natural resource scarcity?-yes, of course it is! **Journal of Environmental Economics and Management**, v. 23, n. 1, p. 91-95, 1992.

DALY, Herman. **A journey of no return, not a circular economy**. Steady State Herald, 2019. Disponível em: https://steadystate.org/a-journey-of-no-return-not-a-circular-economy/. Acesso em: 13 maio 2025.

DARBY, Sarah. **Enough is as good as a feast – sufficiency as policy**. Energy Policy, v. 36, n. 12, p. 4096-4100, 2007.

ELLEN MACARTHUR FOUNDATION. **What Is a Circular Economy?** Disponível em: https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview. Acesso em: 10 mai. 2025.

EUROPEAN ALUMINIUM. **Circular aluminium action plan: a strategy for achieving aluminium's full potential for circular economy by 2030**. Brussels: European Aluminium, 2022.

EUROPEAN COMMISSION. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. **Official Journal of the European Union**, L 315, p. 1-56, 2012.

EUROPEAN COMMISSION. **Closing the loop - An EU action plan for the Circular Economy**. Brussels: European Commission, 2015.

EUROPEAN COMMISSION. Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency. **Official Journal of the European Union**, L 328, p. 210-230, 2018.

EUROPEAN COMMISSION. Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council. **Official Journal of the European Union**, L 328, p. 1-77, 2018.

EUROPEAN COMMISSION. **Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions: The European Green Deal. COM(2019) 640 final**, Brussels, 2019.

EUROPEAN COMMISSION. **A new Circular Economy Action Plan for a cleaner and more competitive Europe.** Brussels: European Commission, 2020.

EUROPEAN COMMISSION. Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency (recast). **Official Journal of the European Union**, L 231, p. 1-129, 2023.

EUROPEAN COMMISSION. **The Clean Transition Dialogues: Clean Industrial Deal**. Brussels: European Commission, 2024.

EUROPEAN COMMISSION. **The Clean Industrial Deal: a joint roadmap for competitiveness and decarbonisation**. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Brussels, 2025.

GEISSDOERFER, Martin et al. The Circular Economy – A New Sustainability Paradigm?. **Journal of Cleaner Production**, v. 143, p. 757-768, 2017.

GENG, Yong; SARKIS, Joseph; ULGIATI, Sergio; ZHANG, Pan. Measuring China's circular economy. **Science**, v. 339, n. 6127, p. 1526-1527, 2013.

GEORGESCU-ROEGEN, Nicholas. **The entropy law and the economic process**. Cambridge, MA: Harvard University Press, 1971.

INTERNATIONAL ALUMINIUM INSTITUTE. **Mapping Study on Aluminium Melt Purification from Post Consumer Scrap**. Brussels: International Aluminium Institute, 2024.

JEVONS, William Stanley. **The Coal Question:** An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal Mines. London: Macmillan, 1865.

JIMENEZ CASANOVA, Paola; PINTO, Jaqueline. Interpreting the Energy Efficiency First Principle: Help or Hindrance for the Hydrogen Economy?. **European Energy and Environmental Law Review**, v. 33, n. 6, p. 274-288, 2024.

KIRCHHERR, Julian, REIKE, Denise, HEKKERT, Marko. Conceptualizing the circular economy: An analysis of 114 definitions. **Resources, Conservation and Recycling**, v. 127, p. 221-232, 2017.

KIRCHHERR, Julian et al. **Breaking the Barriers to the Circular Economy**. Deloitte, 2017.

KORHONEN, Jouni; HONKASALO, Antero; SEPPÄLÄ, Jyri. Circular Economy: The Concept and its Limitations. **Ecological Economics**, v. 143, p. 37-46, 2018.

KOSIR, Ladeja Godina. On transformation of people and the power of networks. In: ALEXANDER, Allen; PASCUCCI, Stefano; CHARNLEY, Fiona (eds.). **Handbook of the Circular Economy**. Berlin: De Gruyter, 2023. p. 85-92.

KOVACIC, Zora; STRAND, Roger; VÖLKER, Thomas. **The circular economy in Europe:** critical perspectives on policies and imaginaries. New York: Routledge, 2020.

LAZAREVIC, David; BRANDÃO, Miguel. The circular economy: a strategy to reconcile economic and environmental objectives? In: BRANDÃO, Miguel; LAZAREVIC, David; FINNVEDEN, Göran (Eds.). **Handbook of the circular economy**. Cheltenham: Edward Elgar Publishing, 2020. p. 8-27.

MARTINEZ ALIER, Joan. La Economía no es circular sino entrópica. **Ecología Política**, n. 49, p. 10-13, 2015. Disponível em: https://www.jornada.com.mx/2015/06/14/opinion/026a1eco

MCDONOUGH, William; BRAUNGART, Michael. **Cradle to cradle:** remaking the way we make things. New York: North Point Press, 2002.

MELLADO RUIZ, Lorenzo. **Desafíos regulatorios de la economía circular azul**. Navarra: Aranzadi, 2023. 272 p.

MILLAR, N.; MCLAUGHLIN, E.; BÖRGER, T. The Circular Economy: swings and roundabouts?. **Ecological Economics**, v. 158, p. 11-19, 2019.

MURRAY, Alan; SKENE, Keith; HAYNES, Kathryn. The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. **Journal of Business Ethics**, v. 140, n. 3, p. 369-380., 2017.

NANCY M. P. BOCKEN. Product design and business model strategies for a circular economy. **Journal of Industrial and Production Engineering**, v. 33, n. 5, p. 308-320, 2016.

OECD. **Resource efficiency, the circular economy, sustainable materials management and trade in metals and minerals**. OECD Trade Policy Papers, n. 245, Paris: OECD Publishing, 2021.

PAENG, Jaesuk; JUDGE, William D.; AZIMI, Gisele. Electrorefining for copper tramp element removal from molten iron for green steelmaking. **Resources, Conservation and Recycling**, v. 206, p. 107654, jul. 2024

PEARCE, David W.; TURNER, R. Kerry. **Economics of natural resources and the environment.** Baltimore: Johns Hopkins University Press, 1989. 392 p.

PRIETO-SANDOVAL, Vanessa; JACA, Carmen; ORMAZABAL, Marta. **Economía circular:** relación con la evolución del concepto de sostenibilidad y estrategias para su implementación. Memoria Investigaciones en Ingeniería, n. 15, p. 86-95, 2017. ISSN 2301-1092. Disponível em: http://revistas.um.edu.uy/index.php/ingenieria/article/view/308/366. Acesso em: 13 mai. 2025.

RAWORTH, Kate. Creating regenerative and distributive economies by design. In: ALEXANDER, Allen; PASCUCCI, Stefano; CHARNLEY, Fiona (org.). **Handbook of the Circular Economy**: transitions and transformation. Berlin; Boston: De Gruyter, 2023. cap. 3.

REIKE, Denise; VERMEULEN, Walter J. V.; WITJES, Sjors. The circular economy: New or Refurbished as CE 3.0? - Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. **Resources, Conservation and Recycling**, v. 135, p. 246-264, 2018.

RITALA, Paavo; BOCKEN, Nancy M. P.; KONIETZKO, Jan. Three lenses on circular business model innovation. In: ALEXANDER, Allen; PASCUCCI, Stefano; CHARNLEY, Fiona (eds.). **Handbook of the Circular Economy**. Berlin: De Gruyter, 2023. p. 175-190.

ROGGENKAMP, Martha. Regulating Energy Efficiency in the European Union. In: **Elgar Encyclopedia of Environmental Law**: Volume IX. Edward Elgar Publishing, 2023.

ROSENOW, Jan; KERN, Florian. EU energy innovation policy: the curious case of energy efficiency. In: LEAL-ARCAS, Rafael; WOUTERS, Jan (eds.). **Research Handbook on EU Energy Law and Policy**. Cheltenham: Edward Elgar, 2023. p. 512-514.

SCHNEIDER, Eric D.; SAGAN, Dorion. **Into the Cool:** Energy Flow, Thermodynamics, and Life. Chicago: University of Chicago Press, 2005.

SCHODER, Daniel; ZIMMERMANN, Thomas; ZINK, Thomas. Degrowth within – Aligning circular economy and strong sustainability narratives. **Resources, Conservation and Recycling**, v. 146, p. 190-191, 2019.

STAHEL, Walter R. **The performance economy**. 2. ed. Hampshire: Palgrave MacMillan, 2010. 376 p.

UNECE. The Circular Economy: **A New Paradigm for Sustainable Development**. Disponível em: https://unece.org/trade/CircularEconomy. Acesso em: 10 mai. 2025.

VALERO, Antonio; VALERO, Alicia. **Thanatia:** the destiny of the Earth's mineral resources. Singapore: World Scientific, 2014. 532.

WATKINS, John P. Veblen's system of conspicuous waste. **Journal of Economic Issues**, v. 53, n. 4, p. 914-927, 2019

YU, Sha; MANDEL, Trevor; THOMAS, Stefan; et al. Applying the Energy Efficiency First principle based on a decision-tree framework. **Energy Efficiency**, v. 15, n. 42, 2022

ZERO WASTE EUROPE. **Reusable vs Single-Use Packaging:** A Review of Environmental Impact. Disponível em: https://zerowasteeurope.eu/wp-content/uploads/2020/12/zwe_reloop_executive-summary_reusable-vs-single-use-packaging_-a-review-of-environmental-impact_en.pdf. Acesso em: 10 mai. 2025.

ZELL-ZIEGLER, Carina; BEST, Benjamin; DALKMANN, Holger; et al. Enough? The role of sufficiency in European energy and climate plans. **Energy Policy**, v. 156, 112431, 2021

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