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The Circular Economy: an Ancient Term that Became Polysemic[1]

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Abstract: Today, Circular Economy (EC) is a popular concept in the business and financial world, among academics, politicians and decision-making bodies, and governmental and non-governmental institutions. Since 2003 has been intensely produced and published academic and non-academic literature. But despite this growing enthusiasm - and as far as we know so far - there are topics related to EC that remain under discussion, perhaps because they have not yet been the subject of sufficiently clarifying and multidisciplinary analysis. In this article, we intend to contribute to the clarification of some of these topics. The topics were chosen according to the questions that were installed in the author's mind of this article as she reviewed the literature on EC (the scientific areas in which the author is included are Environment and Natural Resources Economics and Ecological Economy). The topics under discussion are as follows: 1) Neoclassical economists also use the EC concept; will this be equal to the current concept of EC? 2) Some authors have argued that EC is an entirely new concept; however, the circular functioning of the economy was already described by economists in the 18th century. In the end, we want to demonstrate: 1) That EC is a polysemic term; that is, although the EC of neoclassical economists is different from the current EC, both share a common root: circularity; 2) The term EC is not new because its genesis lies in the 18th century; 3) the current concept of EC is also not new, because it has been described since the 1960s; 4) What is truly new in today's EC is the recognition and internalization of its principles by the business and governmental worlds. To achieve our objective, we were based on the critical analysis of the literature, supported by the theoretical body of conventional neoclassical economics (micro and macro); Ecological and Environmental Economy; and the History of Economic Thought.

Keywords: circular economy; circular model of monetary flows; circular throughput model; linear throughput model.
JEL Classification: A13, O11, O13, O41, O44, Q01, Q50, Q57.

1. Introduction

In the literature, the Circular Economy (CE hereafter) emerges as an alternative to the linear model of extraction-production-consumption-disposal to the extent that this enables a reduction in the effects of overexploitation by anthropogenic activities on the environment – reflecting in the exhaustion of the natural capital stock and irreversible damage to the capacity for self-regeneration – that simultaneously guarantees economic growth, the creation of company value and jobs as well as improvements to the social wellbeing (Ferreira and Fuso-Nerini 2020; Velenturf *et al* 2019; Kalmykova *et al.* 2018; Reike *et al.* 2018; Geissdoerfer *et al.* 2017; Ghisellini *et al.* 2016; Bocken *et al* 2015; EMF 2013).

Furthermore, warnings about waste brought about by the linear model of growth are hardly new to the 21st century. For example, Boulding referred to this growth model as a "cowboy economy", making an analogy with the unbridled consumption of the seemingly unlimited natural resources of the western states of the United States ongoing in the 19th century when these lands were literally invaded by waves of population fleeing the overcrowded East coast

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in search of better living conditions (Boulding 1966). In 1969, Ayres and Kneese[2] (Ayres and Kneese 1969) were already quantifying and predicting how the rise in the tons of material waste coupled with the pollution associated with economic growth based on the linear model would cause climate changes and these would drive significantly negative impacts for anthropogenic activities: "Some experts believe that the latter [CO_2] is likely to show a large relative increase, as much as 50 per cent by the end of the century, possibly giving rise to significant - and probably, on balance, adverse - weather changes“ (*op. cit.*, p. 286).

Indeed, the consequences of the linear model are environmental, economic and social (EMF 2013). On an annual basis, OECD member states account for the generation of 21 billion tons of materials (minerals, fishing, wood, agricultural and foodstuff products, earth and construction materials) over the course of the chain of extraction-transformation (Sustainable Europe Research Institute SERI, *in* EMF 2013). In 2010, the global economic system extracted 65 billion tons of raw materials in a total forecast to rise to 82 billion in 2020. Europe alone produced 2.7 billion tons of waste of which only 40% was subject to recycling, reutilisation by industry and/or consumers or deployed for the production of organic compost. Only one-third of a range of end-of-life metals were recycled at rates equal to or greater than 25% although with significant losses of value even in the case of those metals with high recycling rates, such as copper, aluminium, gold and silver. Only 20% to 30% of the construction materials resulting from the demolition of structures underwent either recycling or reutilisation. The industrial sectors that extract and/or transform resources (and especially in the case of ore) are extremely energy intensive. The currently ongoing process of digitalisation of economies and societies is also energy intensive. The attrition caused by such anthropogenic activities on the environment bears rising repercussions in terms of the declining resilience of the biosphere and correspondingly jeopardising the sustainable production of natural goods and services in the quantities and qualities demanded for economic growth. Therefore, we face a vicious and self-sustaining cycle that resembles the "snowball effect". Ever since 2000, the prices of traded natural resources (especially foodstuffs, non-food agricultural products, energy and minerals) have risen considerably in conjunction with quite dramatic rises in their respective levels of volatility (EMF 2013). The causes generally identified for the rise in these economic and social risks are the following: the pressure of rising demand for the inputs necessary to meet the rise in the rate of wealth as measured by GDP; the growing intensification of natural resource depletion and increased costs for their extraction/utilisation; climate changes; political and social upheavals (e.g. wars, coups, migrations, terrorism, nationalisms, populisms, inequalities); and the liberalisation and innovation of financial markets that have enabled the launching of financial funds that generate their returns through speculative activities involving the prevailing prices of these natural inputs (EMF 2013). Problems such as the patterns of demographic growth, climate changes, the rising economic scarcity of certain natural resources and political and social alterations underpin forecasts that such imbalances are only to worsen and inevitably reflecting on economic growth, patterns of consumption, social wellbeing and the capacity to generate value on behalf of companies (EMF 2013).

The reports on the EC published by the Ellen MacArthur Foundation (EMF hereafter) issue strong warnings as regards these imbalances and the waste caused by the current model of linear growth: "The linear production model incurs unnecessary resource losses in several ways: Waste in the production chain; End-of-life waste; Energy use; Erosion of ecosystems

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[2] Robert Underwood Ayres was an American physics specialist who spent his career researching the application of the physical laws of thermodynamics to economics. He pioneered the material flow model and theories such as Industrial Ecology and the Industrial Metabolism, which he then applied to economic growth. Allen V. Kneese, in turn, was a pioneer in the field of Environmental Economics having been a founding member of the North American institution *Resources for the Future*. His entire research career approached the integration of the physical, natural and social (Sociology and Economics) sciences that would later provide the foundation for the development of Ecological Economics.

services" (EMF 2015; see also Geissdoerfer *et al* 2017). EMF is a British institution founded in 2010 by the companies B&Q, BT, Cisco, National Grid, and Renault. Its main objective involves raising awareness and campaigning for the CE to become a positive and dynamic economic strategy that seeks to bring about the restructuring of the existing economic system – through focusing on production processes such as end-of-pipe solutions – into another type, the restorative economy, leveraged by productive, innovative and creative solutions, specifically designed for the systemic environmental context (https://www.ellenmacarthurfoundation.org/pt/fundacao-ellen-macarthur/a-fundacao, accessed on 21/09/2020). In this new restorative economy, the famous 3 Rs (Reduce, Reutilise and Recycle) are core principles (Murray *et al.* 2017).

The academic and non-academic CE literature (including those reports produced by companies in every sector, including financial and consultancy firms, government institutions, international institutions) hitherto published has seen exponential growth ever since 2002 (Prieto-Sandoval *et al.* 2018; Nobre and Tavares 2017), the date that coincides with the adoption of CE principles by the national development strategy of China (Kalmykova *et al.* 2018). This decision by China rapidly popularised CE whether among academics, company managers, consultants, financiers and government officials and also among institutions (Reike *et al*. 2018; Kirchherr *et al.* 2017); CE currently informs the EU sustainable development strategy (https://ec.europa.eu/environment/circular-economy/, accessed on 21/09/2020) (McDowall *et al.* 2017). The *linear economy* concept also saw its profile in the literature sharply raised within the scope of establishing the difference between the linear patterns of current economic growth *versus* the circularity of the new patterns of growth based on perpetual cycles of movement with a zero net impact on the biosphere due to the effective application of the principles underlying the 3 Rs (Murray *et al*. 2017).

In the literature consulted, there are two topics that especially draw attention. The first stems from the perspective of replacing the linear economy – a creator of waste – by the CE concept *that would have no net negative effect on the environment*. In the literature, the *linear* economy gets generically referenced as an economy organised into traditional structures in the sense of producing products for consumption according to a "take-make-dispose" pattern (*e.g.* EMF 2013): companies extract/use the *natural resources* produced by the biosphere (animals, plants, minerals, fossil fuel energy resources, air, solar radiation, soil, ecosystem services, and so forth) that, combined with anthropogenic *inputs* (human and fixed capital, and *inputs* produced by other companies) in accordance with a determined technology, generate *outputs* – products that shall be purchased by consumers for them to use and extract the intended utility. After usage, the consumers dispose of the component materials into the biosphere, where they end up accumulating and being naturally reassimilated. However, none of the articles and reports studied provided any explicit reference to the origins of the *linear economy* concept nor did they provide any detailed explanation as regards the flows making up the "take-make-dispose" pattern, which contrast with the circular flows described in the circular economy model of orthodox economists. The second topic encapsulates the discussion ongoing about the newness of the CE concept, especially whether or not this is a new concept that emerged into relevance in the business world during the first decade of this century and since 2003 in academia (Prieto-Sandoval *et al.* 2018; Murray *et al*. 2017). The discussion over the putative *newness* of the CE concept (*e.g.* Wautelet 2019; Cardoso 2018; Homrich *et al.* 2018; Kalmikova *et al*. 2018; Murray *et al*. 2017; Bocken *et al*. 2016; Ghisellini *et al*. 2016) may emerge as odd to economists to the extent that orthodox economic theory, environmental economics and ecological economics are also drawn into this debate. We may express such oddness in two questions. Is the current CE concept similar to that of orthodox economics and of environmental and ecological economics? What relationship is there (if any) between the linear economy referenced in articles on "modern" CE and the CE concept taught to any Economics student right in their earliest classes on economic theory? The objective of this article is to find responses to these questions. We here aim to convey how there are only three common and shared points between the CE of the orthodox economists and the CE of the environmentalist and ecologist economists and the current concept. The first stems from the word “circular”; every designation applies the same rationale based on flows that flow either in circles or cycles in order to explain the relationship between production and consumption. The second shared point involves how every designation refers to a relationship between systems of production and consumption within the framework of an economy. The third point in common is how all these fields linguistically apply the same concept - CE. That brings the similarities to a close. We shall demonstrate how the theoretical paradigms on which these designations are founded are distinctive, that the objectives of the models that they produce are different and that the very nature of the flows that they refer to are themselves radically different. In addition, we shall identify how the current CE is not a new theoretical concept at least in linguistic terms.

In order to obtain these objectives, above all based on a review of some of the extensive literature on CE before then advancing with its critical analysis and subsequent discussion in accordance with the objectives here, we base this discussion on the conceptual frameworks of the fields of History of Economic Thought, Macroeconomics, Microeconomics, Environmental Economics and Ecological Economics. For the literature research, we applied the Google Scholar search motor with the following keywords: circular economy; concept. The timeframe defined spanned from 1960 to 2018. We may firstly conclude that the concept is not yet stable as it comes with various different definitions (*e.g.* Reike *et al*. 2018; Korhonen *et al*. 2018 a) and b)). As, for the purposes of these objectives, we necessarily had to work with a current definition of CE and so selected that put forward by the *Ellen MacArthur Foundation* (EMF) in keeping with it having received the most citations and its identification in the literature as the most complete and seminal definition (e.g. Velenturf *et al.* 2019; Geissdoerfer *et al*. 2017; Kirchherr 2017; Lieder and Rashid 2016). In section 2, we set out and critically discuss in some detail this CE definition proposed by the EMF. Subsequently, we set out to grasp when references began emerging to the CE and also clarifying its meaning within the scope of orthodox economic theory (section 3). The literature review also enabled the identification of a degree of controversy about the origins of the current CE concept. Some authors refer to the concept as new while others propose the concept to be historical and stretching back to the 18th century. In order to better perceive this point, we delve into the History of Economic Thought to grasp its origins. Section 4 discusses the CE concept from the perspective of environmental and ecological economists, defines the concept of the linear economy before introducing the Economic-Environment model based on material balance and detailing the similarities and differences between the CE of orthodox economists and the CE of environmental and ecological economists and the concept contemporarily. We finally set out our conclusions.

2. The CE Concept according to the *Ellen MacArthur Foundation*

The *Ellen MacArthur Foundation* (EMF) published three reports on the CE: *Towards the Circular Economy Vol 1: Economic and Business Rationale for an Accelerated Transition* (2012); *Towards the Circular Economy Vol 2: Opportunities for the consumer goods sector* (2013); and *Towards the Circular Economy Vol 3: Economic and Business Rationale for an Accelerated Transition*: *Accelerating the scale-up across global supply chains* (2014). The reports were commissioned from McKinsey for presentation and discussion at the Davos World Economic Forum. Their underlying purpose was to justify the need to adopt a new growth paradigm to ensure more sustainable economies, capable of simultaneously producing value and ensuring employment while also cutting back on waste and the overexploitation of the environment. The reports duly received their public presentation in Davos.

The first report (EMF 2013) encapsulates and defines the concept with the following discussion based upon this definition. The introduction duly explains the reasons behind this choice.

The CE refers to a new industrial economy

The CE refers to an "industrial economy" (EMF 2013 *op. cit* p. 22) with the particular characteristic of "restorative by intention" (*op. cit*., p. 22) to the extent that this "aims to rely on renewable energy; minimises, tracks, and eliminates the use of toxic chemicals, which impair reuse; and eradicates waste through the superior design of materials, products, systems, and, within this, business models".

The report does not define what it understands by an "industrial economy". In the literature, an *industrial economy* represents a stage of economic development that primarily contains activities that combine factors – the *inputs* - (material, energy, services, labour and knowledge) used in the mass production destined for markets – the *outputs* – where they are traded to meet the needs of an increasingly urbanised population and supplying a highly diversified labour force (Stearns 2018). After having attained this stage, economies rapidly evolve into *post-industrial economies* based on services (tertiary sector) and knowledge (quaternary sector) (Stearns 2018). The report defines the CE as something applicable to the *industrial economy* – as this refers to the productive sector, to the technological processes of production and consumption activities – but also affirms that the CE applies to an "industrial economy" which is *new* to the extent of its particular "restorative by intention" characteristic. The CE, as defined by the EMF, thus applies to a stage of economic development, to a *new Industrial Economy*, specifically planned to be restorative and that is not bound only by technological issues to the extent that the concept also proposes the adoption of a new methodological and conceptual framework for studying the functioning of the industrial economy based on systemic analysis and the restructuring of certain classical economic concepts or paradigms: "The term [CE] goes beyond the mechanics of production and consumption of goods and services in the areas that it seeks to redefine (examples include rebuilding capital, including social and natural, and the shift from consumer to user" (EMF 2013, p.22). One of the concepts requiring restructuring is thus "capital", which extends its reference beyond the orthodox concepts of "fixed capital" and "human capital" to also include those of "natural capital[3]" and "social capital". The "final consumer" and "final consumption" represent two of the other paradigms for restructuring and due for replacement by the new paradigms of "user" and "service supplied", respectively (EMF 2013).

The CE as a systemic concept that recognises the existence of physical limitations

In the CE, companies become components in the economic system. The economic system includes two sub-systems: Production (including extraction, transformation, storage, packaging, distribution, collection, recycling, restructuring) and Consumption. These all interconnect through the flows of materials that circulate among them. This clearly constitutes

[3] Hernández-Blanco and Costanza (2018, p. 256) define *natural capital* as "a stock of natural resources (i.e., ecosystems) that yield a flow of goods and services (*i.e.,* ecosystem services)"; therefore including the Natural Environment of the Planet (atmosphere, lithosphere, hydrosphere and biosphere) and the resources and services therein contained (biodiversity, stock of natural resources, ecosystem services). According to these authors, the terms was first applied in 1973 by Schumacher in his book *Small Is Beautiful: A Study of Economics As If People Mattered.* In 1988, Pearce deployed it to affirm the following: "sustainability requires at least a constant stock of natural capital, construed as the set of all environmental assets" (Pearce, D. 1988. Economics, Equity and Sustainable Development. *Futures* **20**(6): 598–605). In 2003, Akerman (Akerman, M. 2003. What Does 'Natural Capital' Do? The Role of Metaphor in Economic Understanding of the Environment. *Environmental Values* **12**(4):431– 448, p. 443) declared that the concept had been subject to redefinition by Constanza and Daly with the objective of: its inclusion in economic analysis; understanding how this relates with economic and environmental systems; and opening the path for a new field of research, Ecological Economics.

a concept perceiving the *industrial economy* as a differentiated set of components (companies and consumers) integrated into differentiated systems (production, consumption), hierarchically organised according to differing levels of aggregation (individual, sectorial, local, regional, national and global). This *industrial economy* is also contained within another system – the Environment – with which it interacts through a network logic - and from which it extracts, or uses, environmental products (natural resources, which include the diverse environmental services produced by natural ecosystems). Within the CE framework, the *industrial economy* functions according to the rules of a living and open system[4] which is contained within another that is closed[5]. The objective of living systems involves the *maximisation of the system as a whole* and not the individualist maximisation of each component[6] (Miller 1973). As a systemic concept, the CE theoretically leverages General System Theory (GST)[7] proposed by Bertalanffy[8]; and, more specifically, the Living Systems Theory (LST)[9] by James Grier Miller (Miller 1973): "The concept of the circular economy is grounded in the study of non-linear systems, particularly living ones." (EMF 2013, p. 22).

The recognition of these physical environmental limitations (an idea absent in the neoclassical economic paradigm) on anthropogenic activities justifies the definition of the CE as a *strategy* that *simultaneously* guarantees: the creation of economic value (monetarily quantifiable); the satisfaction of the basic needs of the population; the promoting of both social wellbeing and environmental sustainability (Bocken *et al* 2015; EMF 2013). The focus on the creation of value of this *new industrial economy* no longer derives from the maximisation of profits obtained from the sale of goods for consumption (which, in the systemic language, corresponds to the

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[4] For example, see the *living system* definition put forward by Miller (1973, p. 69) "Most concrete systems have boundaries which are at least partially permeable, permitting sizeable magnitudes of at least certain sorts of matter-energy or information transmissions to cross them. Such a system is an open system. Such inputs can repair system components that break down and replace energy that is used up" *in* Miller 1973, p. 68.

[5] "A concrete system with impermeable boundaries through which no matter-energy or information transmissions of any sort can occur is a closed system. No actual concrete system is completely closed, so concrete systems are either relatively open or relatively closed. Whatever matter-energy happens to be within the system is all there is going to be. The energy gradually is used up and the matter gradually becomes disorganized. A body in a hermetically sealed casket, for instance, slowly crumbles and its component molecules become intermingle" *in* Miller 1973, p. 68.

[6] "A major consequence of taking insights from living systems is the notion of optimising systems rather than components, which can also be referred to as 'design to fit', in EMAF 2013 p. 22.

[7] GST is a generic theory that may be applied to any scientific field as it incorporates a set of multidisciplinary concepts and principles based on the overall concept of system.

[8] Ludwig von Bertalanffy was an Austrian biologist who described GST in an article published in 1950 (von Bertalanffy, L. 1950. Outline of General System Theory. *The British Journal for the Philosophy of Science,* 1: 139 – 164). In 1968, Bertalanffy and others deepened the systemic theory in the work *General System Theory: Foundations, Development, Applications*, published in 1969 by George Braziller, NY. Various researchers adopted and applied GST to various branches of Science, ranging from mathematics to social networks analysing while also including psychology, biology and gaming theory and with notable contributions for example from: the economist Kenneth Boulding (Boulding, K. 1956. General Systems Theory. *Management Science*, 2, 3: 197-208); the pioneering cybernetics psychiatrist, William Ross Ashbey (Ashbey, W. R. 1991. General Systems Theory as a New Discipline. In *Facets of Systems Science*. International Federation for Systems Research International Series on Systems Science and Engineering, vol 7. Springer: Boston, MA); and the bio-mathematician Anatol Rapoport (Rapoport, A. 1986. *General System Theory*. *Essential Concepts and Applications*. Cybernetics and Systems Series, Taylor and Francis). These four scientists, alongside the neuro-physiologist and behavioural scientist Ralph Gerard, founded the *Society for General Systems Research* in 1957, subsequently renamed the *International Society for the Systems Sciences (ISSS)* in 1987.

[9] LST stems from a set of concepts and principles that explain the functioning and the processes of the evolution of living organisms according to the functioning of non-linear systems: "This analysis of living systems uses concepts of thermodynamics, information theory, cybernetics, and systems engineering, as well as the classical concepts appropriate to each level. The purpose is to produce a description of living structure and process in terms of input and output, flows through systems, steady states, and feedbacks, which will clarify and unify the facts of life" (Miller 1973, p. 87).

individualist maximisation of the components of the system) to become the *maximisation of profit through managing the flow of materials* (of natural resources and products produced by the economic system) made over the course of economic cycles (extraction, production, storage, packaging, distribution, consumption, disposal, collection) and the temporal cycles – which in systemic language relates to maximising the system as a whole:

> "The circular approach contrasts with the traditional linear business model of production of take-make-use dispose and an industrial system largely reliant on fossil fuels, because the aim of the business shifts from generating profits from selling artifacts, to generating profits from the flow of materials and products over time. Circular business models thus can enable economically viable ways to continually reuse products and materials, using renewable resources where possible" (Bocken *et al* 2015, p. 308).

The maximisation of the "industrial economy" system therefore derives from the "…careful management of materials flows" (EMF 2013 p. 22) or "nutrients" circulating among all the components of the economic and environmental systemic structure.

It thus seems clear – even while the report's text does not prove explicit on this point – that any maximising of the Industrial Economy as a *living system*, within the scope of becoming *restorative* and therefore more sustainable, has to emerge out of strategic plans for the systemic management of material flows (*e.g.* business strategy models, new products) in order to ensure the Industrial Economy takes root and fosters synergies across every system and among all the components in the systems interacted with. These strategic plans for managing the material flows are what distinguishes the CE from the traditional economic models – those deemed extraction-transformation-consumption-disposal linear, in which the core business models involve maximising profits through producing and selling new products.

The four core CE principles

The new Industrial Economy incorporates the four core principles that characterise and differentiate this from the linear model based orthodox economic paradigm: eliminating waste, a new business model arising from circuits of biological materials and technical materials; utilisation of renewable energy; and a new paradigm for the "consumer" and "final consumption" concepts (EMF 2013).

The first principle approaches the core CE objective: *eliminating waste (*"First, at its core, a circular economy aims to 'design out' waste'." *op. cit.,* p. 7) in the processes of extraction, transformation, packaging, storage, distribution, collection (for recycling, reutilisation, transformation) and disposal (rubbish, polluting emissions). In the CE, "waste" becomes a management failure. End-of-life products are not waste but rather stocks of materials and energy susceptible to continuous utilisation. The elimination of waste requires two different approaches: through means of a reduction in the quantity of energy and new materials consumed in the production processes; and through replacing fossil fuels with renewable energy sources in addition to the replacement of the economic concept of the final consumer with that of user. These two objectives may be obtained through managing the flows of materials according to the principles of eco-*efficiency* and *eco-effectiveness*[10]. This type of management structures the organisation into networks of material flows that move between

[10] An economic system (that spans the Production, Distribution and Consumption of products) becomes *eco-efficient* when striving to minimise the scale, speed and toxicity of the flows of materials used in their activities but without making any alterations to the linear logic of functioning of *extraction-production-consumption-disposal*. Hence, *eco-efficiency* arises from modifications made to: the type of product produced; the technology applied in its production; the distribution and retail system; and/or alterations to the consumer/producer contract to become a user/supplier contract. Hence, the objective of such *eco-efficiency* is to guarantee the sustainable existence of cycles of production, distribution, commercialisation and usage of products according to a "from the cradle to the cradle" logic (EMF 2013, p. 23.)

and within the economic, environmental and social sub-systems to former *material circles* or *cycles*[11] mutually differentiated and interdependent in accordance with the perspective of cradle-to cradle or C2C[12] and cascade[13] rather than the traditional cradle-to-grave[14] approach. Therefore, the materials (natural resources, intermediate inputs, final products, energy, *etcetera)* should be managed according to the circular logic of production-usage-reutilisation, successively ongoing and in varied forms (in *cycles*), in which each new cycle becomes the "birthplace" for another product. This new industrial system consists of sets of circular and cyclical sub-systems of extraction, transformation, storage, packaging, collection, redistribution and disposal that operate successively and consecutively in networks and interconnected by the flow of materials that continue mutually circulating over a practically infinite duration, replacing the prevailing linear model and essentially establishing the "backbone" of a new industrial economy, hence the CE: "These tight component and product cycles define the circular economy and set it apart from disposal and even recycling where large amounts of embedded energy and labour are lost" (*EMF 2013,* p. 7).

The new economy functions according to the operational logics of *industrial ecology*[15] and the *industrial metabolism*[16] according to which products undergo production for the purposes of long life spans and to be reutilised throughout the cycles organised into systems without any declines in quality. Technologically, these cycles – that Stahel designates as *closed loop systems* rather than *cyclical systems* – fall into two different types[17]. *Loop 1* or the *internal circuit (Stahel 1981)* covers the manufactured products that after having been used by consumers to satisfy their respective utility, are then destined for: either reutilisation ("The use of a product again for the same purpose in its original form or with little enhancement or change" EMF (2013), p.25); or repair or readaptation ("[product refurbishment is [a] process of returning a product to good working condition by replacing or repairing major components that are faulty or close to failure, and making 'cosmetic' changes to update the appearance of a product, such as cleaning, changing fabric, painting or refinishing. EMF (2013), p.25); or remanufacturing ("[Component remanufacturing is a] process of disassembly and recovery at the subassembly or component level. Functioning, reusable parts are taken out of a used product and rebuilt

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11 The conceptual framework and the methodology reorganising the traditional industrial economy into cycles of material flows derives from the works of Stahel (Stahel 1981, 1984, 2010) and Braungartet (Braungartet and McDonough 2002; Braungartet *et al* 2008).

12 The term was proposed by Braungart and McDonough (Braungart and McDonough 2002).

13 The term was proposed by Braungart and McDonough (Braungart and McDonough 2002). *The cascade of components and materials refers to the differentiated usage of materials and products made following the end of life phase, to create new flows of value over the course of time, storing energy and maintaining the quality. This process is however not materially sustainable on account of entropy: "Along the cascade, this material order declines (in other words, entropy increases), in EMF 2013, p. 27).*

14 This term is widely used in the business world for various different contexts – more specifically to analyse the life cycle of products – and thereby referring to the traditional and linear process of extraction-production-disposal.

15 According to Erkman (1997), *Industrial Ecology* refers to a theory that studies the productive economic sector as if this were a natural or biological ecosystem. The core purpose of this theoretical model involves grasping how the industrial system works; its system of regulation; how this interacts with the environmental system or the biosphere; and the ways in which this might be subject to restructuring in order to function as a biological ecosystem. The term began emerging in the literature in the 1970s but the decisive contribution made towards disseminating this model was attributed to Robert Frosch and Nicolas Gallopoulos (1989).

16 According to Erkman (1997), *Industrial Metabolism* incorporates a theory studying the flows of materials and energy related with human activities, which circulate from the extraction phase (of materials) through to their final reintegration into the biological cycles of the environmental system and to this end applying an analytical and descriptive model based on the materials-balance principle. This principle was first studied by Robert Ayres and Allen Kneese in the 1960s (Ayres and Kneese 1969) and with the term Industrial Metabolism first entering the public domain in the 1980s in a work by Robert Ayres (Ayres 1994).

17 The *closed circuit* term was proposed by Stahel (Stahel *op. cit*) who was also responsible for separating the cycles (or circuits) into two distinctive technological types: the internal cycle (circuit) or the cycle (circuit) 1, which refers to the reutilisation of manufactured products, and the external cycle (circuit) or cycle (circuit) 2, which incorporates the recycling of used materials.

into a new one. This process includes quality assurance and potential enhancements or changes to the components", EMF (2013), p.25). The reutilisation, repair and remanufacture of products with *long life cycles* reduces the physical volume and the speed of circulation of new materials over the course of the long circuit of extraction-production-recycling or disposal as waste simultaneously to cutting the waste generated throughout the extent of the processes of utilisation, production, distribution and packaging. The *reutilisation* dimension intrinsically interlinks with the extent of the product life cycle. Loop 2 or the *external circuit* (Stahel 1981) spans the manufactured products that, at their end-of-life, return to the productive sector for recycling (with three different recycling processes: *functional*, *downcycling* and *upcycling* ("[functional recycling is a] process of recovering materials for the original purpose or for other purposes, excluding energy recovery; [downcycling is a] process of converting materials into new materials of lesser quality and reduced functionality; [upcycling is a] process of converting materials into new materials of higher quality and increased functionality" EMF 2013, p. 25). Recycling closes the flow circuit between the product in the end-of-life stage and its return to the productive system but without having any influence over the speed of the circulation of flows of new materials (Stahel 1981), which may even rise (rather than fall). This stems from how, should business managers and societies interiorise that recycling creates value and employment, then there will be a general interest in maintaining the production of waste in order to guarantee the sustainability of the recycling sector.

Loop 1 puts into practice the core strategic objective of the CE - the elimination of waste - via a *reduction in the speed of circulation of new resource flows*. This reduction comes about through new product designs with longer lasting life cycles and that ensure reutilisation without any loss of quality. Loop *2* closes the circuit between the end-of-life product produced according to the logic of the traditional linear model and production. In Bocken *et al* 2015 (with these authors grounding their studies in the works of Stahel, Braungart and McDonough, and Braungart *et al. op. cit.*), we may encounter a classification of the product design strategies as well as those for circular new business models and setting out various references to texts that enable the deepening of these strategies[18]. Both the former and the latter undergo classification into two groups: the first group includes the strategies and products that delay the new resource circuits and with the second including the strategies, products and businesses that close these circuits. The strategies with new products that slow down the circuit speeds include the production of goods with longer life spans (products specifically designed to bring about empathy in consumers; long lasting products; products that guarantee good working standards over time) and planning the full extent of the life cycle through the introduction of service circuits purpose designed for this objective, such as reutilisation of the product itself, the maintenance, repair and upgrades or combinations of all these. The new product strategies that close the circuits are those incorporating a *cradle to cradle* (C2C) design logic and include the restructuring of the production of products organised into technical and biological circuits, and products that facilitate their dismantling and reconstruction. The strategies for new business models – here understanding *business model* as the means by which a company sets about developing its business) (Magretta 2002) – that slow down the speed of circuit flows cover: type of product/service provided by the company; such as the creation of value and how this value is captured (Bocken and Short 2016). This correspondingly includes access and performance models (the consumer acquires the right to use the product but not the right of ownership over that good); models extending the value of products (considering the waste value of the product and not merely its sale price to the consumer); the classical long life product (a high quality product reusable over time produced with resistant

[18] We do not go further into these strategies as that falls beyond our remit here. Nevertheless, we believe their referencing holds importance as they are new in the sense that, if duly applied, they would enable the restructuring of linear industrial economies into circular economies, thus internalising within their scope the notion of physical limitations existing on economic growth.

materials). The strategies for new business models that close these circuits include all those processes that enable the capture of value based on the waste sub-products, wastage – with the final destination otherwise being the rubbish heap - and industrial symbiosis (for further details on this concept, see, for example, Velenturf and Jensen 2015).

In addition to the reorganisation of the Industrial Economy, there is a third strategy for eliminating waste that differs from the two above (Bocken *et al.* 2016). The core objective of this third strategy, put forward by Braungart *et al.* (*op. cit.*), is the reduction in the quantity of new resources used both during the various production processes and those actually contained in the final products. Hence, this involves nurturing the eco-efficiency of the flow circuits within the cradle-grave logic that bears consequences including *narrowing the loops*[19]. This constricting of the circuits does not necessarily impact on the speed of the flows as the process is not defined in accordance with the *time of circulation* variable; the process even accepts, and without ever jeopardising or even questioning, the speed of new material flows in the linear model. This effectively ensures that any CE implementation strategy based exclusively on eco-efficiency, thus on *narrowing the loops*, may generate a contrary effect to that intended through potentially intensifying but not reducing the speed of new material flows (greater eco-efficiency means cheaper and more competitive products; thus, increasing supply and the intensification of demand and successively onwards) and, consequently, to the greater consumption of new resources (Bocken *et al* 2015).

In summary, the implementation of a new CE type industrial economy implicitly requires a radical change in relation to the current linear model of production/consumption: "The move to a circular economy model is an example of a radical change, which will require a new way of thinking and doing business" (Bocken *et al* 2016, p. 312). Such a radical change extends across the integrated reorganisation of flows of new materials and products throughout long and closed circuits, planned within the scope of management methodologies for the new business models, new products and new means of consumption in keeping with a systemic perspective: "…the move to a circular economy is inherently complex and "systems thinking" is essential to understand the wider impact of the changes in business models and design, especially as these are interrelated" (Bocken *et al* 2015, p. 315).

The second principle on which the EMF grounds its CE concept stems directly from the first and encapsulates the type of materials that establish the flows in the loops. Hence, these flows are of two types in accordance with the characteristics of the products they then compose: the *biological flows* and the *technical flows* (with the latter adopted by the EMF from the classification put forward by Braungart, M. and McDonough, W. 2002). The biological constitutes flows of biodegradable materials that return to the biosphere for re-assimilation and recover their value as biological nutrients which, in turn, re-feed into the ecosystems, infinitely enabling the maintenance and reproduction of natural capital without either disorder or entropy. These flows make up the *biological cycle of material flows* and refer to renewable and biodegradable materials. The technical flows include non-renewable and non-biodegradable materials (or those that only bio-degrade at the end of an excessively long timeframe according to the human time scale) but that may, alternatively, be continually reused in different closed circuits (closed-loops), without any significant loss of quality and without returning to the biosphere. These flows provide for the *technical cycle of material*

[19] This concept was presented in 1998 by von Weizsäcker, Lovins and Lovins (see, for example, von Weizsäcker, E. U, Lovins, A. B. and Lovins L. H.. 2014. *Factor Four; Doubling Wealth – Halving Resource Use. The New Report to the Club of Rome*, Springer, Cham.). Von Weizsäcker founded the Wuppertal Institute for Climate, Environment and Energy. The book generated a significant impact due to the technological examples put forward to apply the concept of eco-efficiency to the business world and that for example included energy efficient vehicle and low energy consumption housing.

flows. The biological flows produce *products for consumption* and the technical flows result in *products for usage.* The former are products made from biodegradable materials that may broadly be disposed of directly into the biosphere without undermining the resilience of the prevailing ecosystems. The *products for use* (for example, vehicles, machinery, construction materials, clothing, etcetera) include those produced through recourse to *technical nutrients;* and are specifically designed to be subject to continuous reutilisation in closed and consecutive cycles. The value of the *products for use* does not therefore reside in the physical product in itself but rather in the *type of use* (in the *service*) that this provides to the *user* (consumer). Examples of durable products include buildings, machinery, utensils and infrastructures.

The third principle refers to the usage of renewable energy throughout the perimeter of these circuits/loops and all economic activities for extraction, transformation, storage, packaging, distribution, consumption, collection and recovery. The increase in demand for renewable energy reduces the demand pressures on the stock of non-renewable energy resources, thereby contributing to boosting the resilience of a set of natural ecosystems and the reduction on the dependence of the economic system on the environmental system.

Finally, the fourth and last principle derives from the change made to the classical paradigm for the consumer concept and for the consumer-producer relationship. In the classical economic paradigm, the *consumer* is the actor that acquires from the *producer* a right to the full usage of a product produced, including its ownership as regards whenever purchasing it on the market. The product is purchased from the producer to be applied in the way consumers understand is the most appropriate to satisfying their utility. At the end, they dispose of the product without any concern over the type of end the product shall face. To the producer, this final product destination is also not a matter of interest as the product was produced and sold. This process characterises the current linear model. In the new paradigm, the consumer is the *user* of a product. Hence, what the consumer acquires from the product market from the producer is then the *right to use* the product for the satisfaction of their individual needs (through leasing, renting, systems of sharing), without this usage ever preventing the scope of opportunity for its future reutilisation. The right of usage *does not include the right of ownership* of the consumer over the product, thus, this does *not include the right to dispose*: "For *technical nutrients*, the circular economy largely replaces the concept of a *consumer* with that of a *user*. This calls for a new contract between businesses and their customers based on product performance. Unlike in today's 'buy-and-consume' economy, durable products are leased, rented, or shared wherever possible. If they are sold, there are incentives or *agreements* in place to ensure their return and thereafter the reuse of the product or its components and materials at the end of its period of primary use." (*op. cit*., p. 7). According to the logic of the CE, the disposal of a product as waste (whether in the form of garbage, effluents or emissions) means *wastage* of the labour, the energy, the intermediate inputs and the natural resources applied to its production, packaging, storage, distribution, final consumption and disposal.

What we may conclude

The first conclusion arises from the core objective of the CE. It would seem clear that this primary aim involves restructuring the workings of the industrial economy to render it more sustainable through the *elimination of all forms of waste* that characterise the current production and consumption processes under the linear model. That which today gets referred to as polluting emissions (gases, liquids, dusts) and sub-products, or the production of garbage – which are generically disposed of into the biosphere to undergo natural re-assimilation – are to undergo substantial reductions. Therefore, the CE should not be confused simply with recycling or with the disposal/treatment of waste and pollutants. The EMF definition is perfectly clear when affirming: " … set it [the CE] apart from disposal and even recycling where large amounts of embedded energy and labour are lost.". Indeed, various authors have already recognised this (*e.g.* Bocken *et al* 2015; Ghisellini *et al* 2016).

The second conclusion derives from how the CE as proposed by the EMF does not appear to be a theory, thus, a plausible and scientifically accepted principle or set of principles that explain a phenomenon and susceptible to testing and application in forecasts about their functioning in the real world (Merriam-Webster 2020, adapted). The discussion around whether the CE does or does not constitute a theory is not the main object of this article and hence beyond our scope to develop it further here. We shall simply cite some of the articles on which we may base our affirmation, including Ferreira and Fuso-Nerini (2020), Korhonen *et al.* 2018 (a, b), Kalmykov *et al.* (2018), Prieto – Sandoval *et al*. (2018), Reike *et al.* (2018), Geissdoerfer *et al.* (2017), Kirchherr *et al.* (2017), Ghisellini *et al.* (2016) and Andersen (2007). All these publications make reference to the lack of definition of the CE concept as deployed in the literature whether in articles adopting theoretical, methodological or empirical analytical approaches: "… not a single study until now, as far as we are aware, has comprehensively and systematically investigated CE definitions (Kirchherr *et al.* 2017, p. 221)". Furthermore, approaches to the CE have been highly diverse. For example, they have focused on: defining the CE; on its relationship with the sustainable development concept; case studies at the level of company or sector; methodologies for deploying the CE at the level of companies, sectors, districts, nations, regions, globally; *etcetera* (Ghisellini *et al.* 2016). This reflects in how the very conception of the CE – its definition and scope – varies from article to article and with the literature characterised by the proliferation of articles with the most diverse objectives, methods and case studies with the conceptual frameworks remaining not clearly defined. Hence, the CE cannot, in itself, be deemed a *theory*: "However, we argue that the dissemination of the circular economy is hampered because the CE field is currently populated by diverging approaches. Also, no analysis of the available CE implementation strategies and the CE implementation experience have been developed yet, thus, in particular, precluding effective CE implementation and putting the planned CE investments at risk" (Kalmykova *et al* 2018, p. 190). Nevertheless, the CE may at least represent a *strategy* or a *method:* "… [CE is] a method worked out in advance for achieving some objective, the means or procedure for doing something." (Merriam-Webster, 2020). The EMF definition of CE would seem clear on this matter when identifying the *three* structural *pillars* of the methodology for *managing the uses* of natural capital (thus, of renewable and non-renewable resources produced by natural ecosystems that includes environmental goods and services) undertaken in due respect for the physical limits ("preserve and enhance natural capital") (EMF 2015 p. 23): the "… careful management of material flows"; the *optimisation of resource usage* within the framework of ending/reducing waste ("optimize resource yields"); and the *effective adoption of a systemic approach to the functioning of economies* through the monitoring, evaluation and forecasting of negative externalities in terms of water, air, soil, pollution, congestion, health and climate change ("Foster system effectiveness") carried out through the applications of appropriate metrics.

The third conclusion encapsulates how the CE concept most certainly extends beyond just recycling or eco-efficiency (Ferreira and Fuso-Nerini 2020, Kalmykova *et al*. 2018, Prieto-Sandoval *et al.* 2018, Kirchherr *et al*. 2017, Ghisellini *et al.* 2016, EMF 2013). This above all reflects how this strategy seeks to promote the functioning of the economy in cycles as if a living system and thereby maintaining a perpetual balance and without the production of material, energy or information waste (e.g. cycles of water, of nitrogen, of carbon, *etcetera*): "In nature, nothing gets wasted and everything undergoes transformation" (Lavoisier). Hence, the cycle is therefore the most crucial facet of the CE: the economic system should operate according to cycles. The diagram in Figure 1 generically describes the functioning of an economic system according to a circular (or cyclical) logic.

The fourth conclusion is that the CE does not apply only to companies in isolation. From a microeconomic perspective, “circular” companies hold the objective of maximising their value through the improvement of processes, the adopting of new business models and ecologically innovative production solutions (Ormazabal *et al*. 2016). In keeping with its nature as a systemic strategy, this applies to higher levels of aggregation: at the meso level (including integrating companies in an industrial symbiosis that benefits not only the regional and local economy but also the host natural environment [Geng *et al*. 2012]); and the macro level (with the focus on fostering the integrated development of eco-cities, eco-municipalities and eco-districts through environmental, economic, social and institutional public policies [Yuan *et al*. 2006]). As a concept that studies the functioning of the Industrial Economy according to the logic of the *living systems theory*, successful application of the CE requires planning in an integrated fashion and therefore necessarily *strategic*: “… companies need to start with an overall vision before developing their circular business model and design strategies in detail” (Bocken *et al* 2016, p. 317); “CE has most often been considered only as an approach to more appropriate waste management. Such a very limited point of view may lead the CE to fail, in that some recycling, reuse

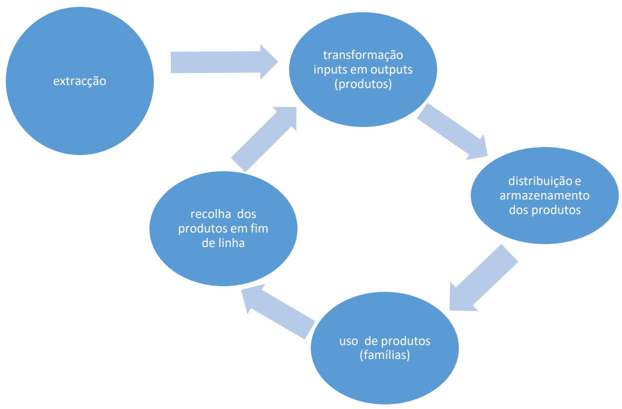

Figure 1 Generic Representation of an Economic Cycle according to the CE principles

or recovery options may either be not appropriate in a given context while … All in all, the challenge ahead towards a preventative and regenerative eco-industrial development … requires a broader and much more comprehensive look at the design of radically alternative solutions, over the entire life cycle of any process as well as at the interaction between the process and the environment and the economy in which it is embedded, … CE has the potential to understand and implement radically new patterns and help society reach increased sustainability and wellbeing at low or no material, energy and environmental costs” (Ghisellini *et al*. 2016, p. 12). “The strategy [the CE strategy] requires complete reform of the whole system of human activity, which includes both production processes and consumption activities” (Yuan *et al*. 2006, p. 5).

The primary objective of this article is to discuss the differences and similarities between the *circular economy* referred to by orthodox economists and the *circular economy* referred to by environmentalist and ecological economists and the EMF. In the following sections, we set out how the CE is no new concept in two different ways: it is not nominally new as the concept has been in use by economists ever since the 18th century to designate the circular economic model for the flows of exchange values; and nor is it new in terms of content as its foundations span a set of theories, methods and concepts drawn from various scientific fields that have been undergoing development for decades: “The CE notion draws on many other concepts, established decades ago, such as the spaceman economy (Boulding [1966]), limits to growth (Club of Rome [Meadows *et al*. 1972]), stationary state [Daily 1996; Classical Economists], Performance Economy (Stahel [2010]), Industrial Ecology (Frosch and Gallopoulos]) and "cradle-to-cradle" (Braungart *et al.* […]), among others." (Kalmykova *et al*. p. 194). In addition to these, we may also highlight the theoretical and methodological contributions made by the scientific fields of Environmental Economics – the material balance model of Ayres and Kneese (1969) - and Ecological Economics - Daily (1996); Pearce and Turner (1990); Boulding (1966); Georgescu‐Roegen (1986) - (Wautelet 2019).

3. The CE in the orthodox economic paradigm: the Circular Economic Model of the Flow of Exchange Value

The idea of an economy built up out of components mutually connected by a *flow* of some type is far from any novelty to economists. Orthodox economists deploy a macroeconomic model for flows of costs and production – or the model in the *Keynesian* economic circuit – to explain the workings and the growth of an economy. Such models are constructed as if a *closed circuit of flows of exchange values measured in whatever currency* circulates between producers and consumers. They underpin national accountancy systems, corporate accountancy systems and macroeconomic models of inputs-outputs. In this section, we detail this model and discuss the differences in relationship to the CE defined by the EMF. We aim to conclude that the CE represented by this model is not the CE that is currently attracting such great interest. There are only three similarities: the analytical method, based on systemic theory; the circular movement of flows moving between and within the components of the economic system; and the name the model gets called.

The historical roots of the name date back to the 18th century, more precisely to the Mercantilist period (Cardoso 2018). In 1705, John Law[20] became the first economist known to have deployed a *circular process* to explain the impact of the expansion of the monetary mass in a situation facing unemployment and the under-utilisation of resources even while never having made any specific reference as such (Murphy 2006). It was Richard Cantillon[21] who, in 1730, explicitly set out a *circular model of flows* to explain the distribution of agricultural production among land owners, leaseholders and labourers. The circular model of flows put forward by Cantillon has been developed, improved and adopted internationally through to contemporary times. In 1758, the physiocrat François Quesnay developed this and depicted it schematically in his *Tableau Économique* in what today gains recognition within the framework of the history of economic thought as the first formal and precise description of the functioning of an economy according to the logic of *systemic interdependence*. Later, this *Quesnay Table* again was subject to reference and important development by Karl Marx in his work *The Capital* (2nd volume) in which he referred to how economies reproduce according to the logic of a *succession of recurrent cyclical processes that involve production, exchange (commerce) and consumption, among which capital flowed*. However, the great development in the circular economic model of flows came from John Maynard Keynes[22] in the 1930s and which later, Leontief, writing in the 1980s, explicitly designated as a CE[23] and deployed this in order to formulate his *model of input-output* that explains the workings of production and consumption through an integrated approach. A simplified version of the circular economic model of flows, as appears in the majority of textbooks on economic theory, features in the diagram in Figure 2.

[20] Law, J. 1705. *Money and Trade Considered: With a Proposal for Supplying the Nation with Money*, Glasgow: A. Foulis: Edinburgh. https://archive.org/details/moneytradeconsid00lawj/page/8/mode/2up (last accessed 5th March 2020).
[21] Cantillon, R. 1730. *Essay on the Nature of Trade in General*.
[22] Keynes, J. M. 1936. *The General Theory of Employment, Interest and Money*. Macmillan (reprinted 2007): London.
[23] Leontief, W. 1991. The Economy as a Circular Flow. *Structural Change and Economic Dynamics*, **2**(1): 181 – 211.

In Figure 2, the external rectangle defined by the line in *bold* frames the working of an economy according to a systemic logic. The components of an economic system are the companies, the consumers and the markets. Companies provide products for the final consumption by households and place them onto the Product Market – the *Supply* – where they get purchased by households to satisfy their utility through consumption – the *Demand*. In turn, households provide companies with their factors of production such as labour, land and capital (savings) supplying them to the Factors Market where they are acquired by companies to deploy them in the production of outputs[24]. This flow of products is depicted by the external lines that circulate clockwise; representing a *real flow* because within there are flows of goods and services which are products with real origins. In the contrary direction to this real flow we have the *monetary flows,* depicted by the internal lines. The factor of production transactions take place in the Factors Market. These transactions generate flows of earnings that accumulate for households as remuneration (in the form of salaries, rents and profits) due to the demand for the factors of production; this flow of earnings is equivalent to the flow of costs incurred by companies in their acquisition of factors of production.

ECONOMIC SYSTEM

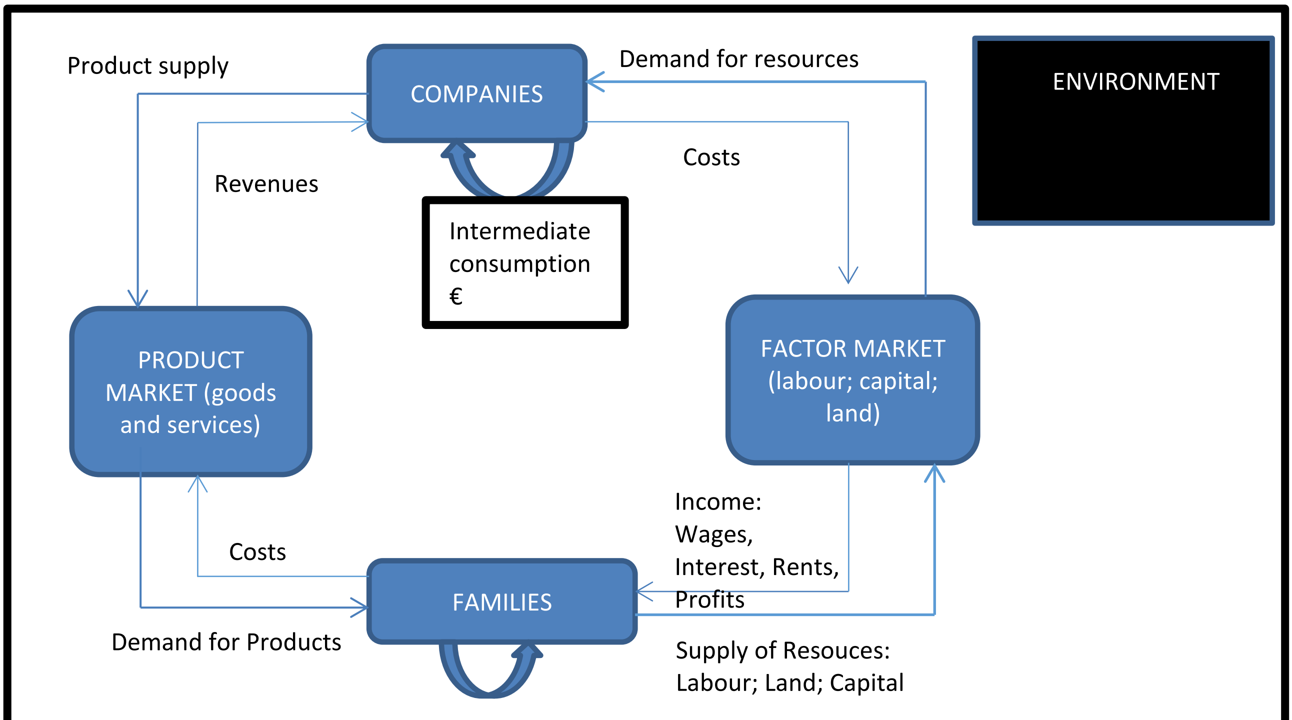

Figure 2 Simplified Circular Model of Flows of Costs and Production: flows of exchange values for *factors and outputs*

In the same fashion, the transaction of products made within the scope of the respective market generates another flow of money – the costs incurred by families in their purchases of

[24] Following the purchase of the factors of production supplied by families, companies combine them in determined quantities, along with other factors of production supplied by the productive system itself. The costs incurred by Companies in acquiring this type of productive factor - designated intermediary *inputs* – are entitled *Intermediate Consumption*. The intermediary *inputs* are then combined with other factors of production according to a particular "recipe for combination" that underpins their efficiency in the quantity of *inputs* applied in the production of products. The relationship between the quantity of *inputs* and the quantity of products produced or the *outputs* is portrayed by the economists through the Production Function that also incorporates the Technology consumed in the production process.

products – which revert to companies in the form of revenues. These two flows combined constitute that which orthodox economists designate as the *circular flow of exchange values*. Despite their clear material basis, these flows are not evaluated in physical units (tons; hours; kilometres; litres or by period of time) but rather by monetary units that, in essence, represent a physical measurement of the exchange values.

As stated above, the prices of the products traded in markets (the exchange values) play a fundamental role within the context of the model. When markets are competitive,[25] the prices (or the unit exchange value of the products) are established by the interactions between the volumes of products supplied and demanded by the markets without experiencing any interference on behalf of the consumers or producers: when the quantities available (supply) are excessive/insufficient, prices fall/rise; when the quantities required (demand) are excessive/insufficient, prices rise/fall. The quantity supplied varies in the same direction as the price and expanding whenever the latter rises and falling back with lower price levels; the level of demand varies in the inverse direction to the price, contracting when the prices head upwards and increasing whenever prices falls (*law of demand*). Multiplying the quantity of productive factors owned by households at the respective prices, provides a figure for family/household income. Adding up the income from all households provides the national income. Similarly, summing up the quantities of all products produced by companies multiplied by their respective prices provides the national output. Out of convention (the national accountancy system based on the circular model of monetary flows), the National Output is equal to the National Income. The economic model for the flow of exchange values is circular and, due to its construction, is a *continuous motor*. This characteristic is guaranteed *a priori* by the accountancy equality between the products produced and household income: households will always have enough earnings to buy the outputs of companies; the sales of company products generates the wealth that is distributed to households through remuneration for the factors of production; and thus successively and eternally, in a continuous circular movement (Say's Law or the Law of Markets[26]). However, the model is clearly not immune to events that may cause disruptions or imbalances. For example, households may not want to buy all of the products supplied by companies; or they may not wish to spend all of their income on purchases and opting instead for savings; or not all the products are for sale in the domestic market; *etcetera*. Nevertheless, what the model guarantees is that any alterations to the flows automatically generates compensatory changes in the other in order to maintain the model in balance. These compensatory changes stem from the variations in the prices for product and factor markets and reflect real variations in supply and demand for consumer goods and the factors of production. In the most complete versions of the circular model – that include exports/imports, the state and public expenditure and the financial markets – the circular model of exchange value is of great utility to economists because this provides a means of integrating micro and macroeconomic phenomena and formulating the economic policies (monetary, fiscal, *etcetera*) most appropriate to minimising the imbalances that cause unemployment, inflation, *etcetera*.

Both the flow scale and the speed of circulation vary in accordance with the size and composition of the population; the technology, labour productivity; the accumulation of capital; the occurrence of natural phenomena (droughts, floods, earthquakes, climate change, *etcetera*); and with changes to the prevailing social patterns (consumption habits, fashion, *etcetera*). At the microeconomic level (companies and consumers approached individually), there are limits on the expansion of monetary flows imposed by the marginal criteria of

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[25] This assumes that markets are both competitive and operate according to perfect rules of competition constituting the core hypotheses of fundamental neoclassical theory.

[26] Jean Baptiste Say. 1834. *A Treatise on Political Economy: Or the Production, Distribution, and Consumption of Wealth*, 6th edition Americana. Grigg and Elliot: Pennsylvania. Available at https://archive.org/details/atreatiseonpoli00saygoog/page/n14/mode/2up. (accessed on 5 August 2020).

microeconomic efficiency according to which the total quantities produced (consumed) by companies (consumers) are efficient only up to the point where the revenues (benefits) for the final physical unit sold (purchased) equals the cost (expenditure) of its production (purchase). At the macroeconomic level, nevertheless, there are no brakes on the growth in the flows; or rather restrictions do exist but in the form of the Production Possibility Frontier (PPF)[27]. However, the PPF may always be expanded through raising the capital stock level and technological innovation. According to neoclassical economists, the accumulation of consumer goods and capital is synonymous with the creation of wealth and, therefore, 'the more, the merrier'. For development to take place, there has to be continuous growth, thus intensifying the monetary flows. They ignore the presence of physical limitations to economic growth as they assume the market and technological innovation shall be able to overcome all of the problems arising from such *scarcity*: whether through technological replacement; changes to the factors of production or through the markets via price fluctuations.

The circular economic model of exchange values is a *closed* model in the sense that the economy gets depicted in an isolated fashion and without any explicit relationship with the environment system on which, when all is said and done, it still depends. The soil, the space, the metals, rocks, plants, animals, the effluents, the garbage; such aspects do not fall within the scope of this model. The environment emerges as a type of ghostly black box with its existence going ignored (the black box is our introduction here; this is not represented in the economic models of circular monetary flows). In the neoclassical paradigm, the economic system dominates and contains the environmental system (note how the rectangle for the environment is positioned within the external rectangle) and which does not consider this worthy of reference nor a factor of relevant risk for two reasons. The first interrelates with the perception that economists hold as regards the physical availability of natural resources. Natural resources are deemed eternal as their supply is almost unlimited and therefore not running any risk of scarcity. Furthermore, even when their stocks are on the verge of depletion, investment in new technologies shall always enable the establishing of a balance in the monetary flow model and raising the efficiency of production through reducing the quantities of natural resources consumed. Hence, the capital produced by humans always serves to replace the environmental resource; thus, there shall never be any scarcity and the circular flow model shall maintain its due balance. The second reason is economic in nature and stems from how a substantial proportion of natural resources are public goods (therefore, non-rivals and non-excludable). Therefore, they are not tradeable as they do not come with prices that reflect their exchange value in terms of supply and demand. Nevertheless, many of these resources are susceptible to market trading despite displaying the characteristics of public goods (thus, they represent almost-public or semi-public goods) – as is the case of common use (or common good) resources; for example, wild fish, the water from rivers and springs, the wood in forests or minerals. As they have a price, economic actors evaluate these resources in terms of their exchange value and not by their available physical dimension or the quality of a real stock. However, their price (hence, the average income for the actor exploiting the resource) is unable to incorporate the true physical reality of the physical depletion of stocks facing situations of overexploitation and instead disguises this under the cloak of positive average monetary profitability[28]: according to *market law*, the price of a scarce natural

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[27] The Production Possibility Frontier represents an economic model applied to study efficient exchanges among products in a simplified economy that produces only two products and assumes the prior endowment of productive resources. The Frontier itself is a line that represents all of the efficient combinations for quantities of both products, hence, those produced while exhausting the productive resources in the economy (hence, in efficiency, there is neither waste nor excess production). The Frontier may be expanded (or retracted) through variations in the capital stock (thus, raising productivity) and technological innovation (see, for example, Krugman, P. and Wells, R.. 2009. *Microeconomics*, 2nd edition, Worth Publishers: USA).

[28] Environmental economists, thus those economists who integrate into the neoclassical theoretical paradigm factors such as the question of natural capital and the respective physical limits, to this end designate this the

resource naturally rises in keeping with any increase in its scarcity; therefore, the average monetary returns to the actor extracting it; exploration of this resource shall then continue all the while the average earnings remain in excess of average exploitation costs. Thus, the rise in the price for any resource provides an incentive for its continued exploitation even when faced by evidence of irreversible rupture in its respective supply. By the time the price of a resource attains such a level as to reduce its demand to zero, that resource may have already entered into extinction because its natural capacity for regeneration has already been irreversibly impacted by the overexploitation to which it was subject in the meanwhile. In the monetary flow model, what gets accounted for is the rise in wealth brought about by extraction of the resource and its market due to the significant increase in its price (the exchange value), despite the ongoing reduction in the physical stock through to the limit of depletion and extinction. The physical situation of resource stocks and the state of the capacity for regeneration and recovery of ecosystems in response to the shocks caused by anthropogenic activities upon them, does not therefore appear as an insurmountable risk from the neoclassical economic perspective. Natural resources "touch down" in markets, apparently appearing out of nothing; or more accurately, those that "touch down" in markets are only those that are extracted (*e.g.* metals), cultivated (*e.g.* trees), captured (*e.g.* fish), or those stemming from ownership rights susceptible to transaction (*e.g.* land) but never without recognising that their production arises from the activities of the environmental system and not those of humans. The concept of *natural capital* thus does not exist. For example, in the neoclassical paradigm and in national accountancy systems, Forestry is the sector that produces wood. Nevertheless, the surrounding environment *produces* the wood: the economic actors limit their role to planting the trees, felling and distributing them. The Fishing sector does *not produce* fish; that is down to the prevailing hydrosphere; and so forth. The environmental services (photosynthesis, carbon capture, establishing of humus, maintaining and regulating the water cycle, *etcetera*) simply get ignored as the majority are not market traded and therefore do not have any price.

The circular monetary flow model also ignores how companies do not only produce the products desired and that consumers do not just consume them. They all produce *undesired* or *bad products* (a term that extends to include all forms of pollution and garbage). The *bad* end up with one of two outcomes: some are disposed of into the biosphere; others are disposed of as waste to be later collected and reutilised (the physical goods themselves or the materials they are made from), once again re-enter the production system as inputs. However, only those *bads* that hold an exchange value – and thus generate wealth due to their transactable nature, gain an exchange value – make it into the circular monetary flow model. The others are invisible to economic actors despite their essential role in production and consumption processes.

We may hence conclude that the functioning of an economy as described by the theoretical circular flow of exchange values model explains only that *x euros spent*, reappears as *x euros earned*; and this circular movement generates flows of wealth that grow infinitely. Given its sealed dimensions, this model depicts the economy as an isolated and self-sufficient entity not subject to any physical restrictions that might limit its growth. The environment that produces the natural capital on which the economy depends gets ignored or, at best, generically represented in some of the theoretical growth models merely by the L (Land) variable evaluated at market prices. At the microeconomic level, only the market traded natural resources - and thus generating exchange value – gain explicit recognition in the decisions of economic actors in keeping with their capacity to generate added value (wealth measured in monetary terms). Despite their real physical foundations, the flows are measuring according to

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Tragedy of the Commons. This economic concept explains the effects of the economic overexploitation of commonly held natural resources (rival but not-excludable, or only excluded with difficulty, public goods) such as wild fish or soils for particular usages, for example.

their exchange value in currency terms and not by their physical dimension. Thus, this openly ignores the physical limitations on natural capital. This also ignores how the sector of production and consumers both produce *bads* (pollution and waste). This furthermore ignores how these *bads* are discharged into the environment and correspondingly also ignoring the ways and speeds of such discharges except in those cases susceptible to recycling as this creates value. Finally, this also ignores the economic and social consequences of the overexploitation of natural resources. The neoclassical model effectively describes the functioning of the economy as a system made up of various components at the micro and macro levels, mutually interconnected through circular movements, sustained and eternally balanced by the flows of exchange values: hence, as a *continuous driver*.

4. The CE, the relationship between the economy and the environment and the Material Flow Model

The CE represented in the abstract model discussed in section 3 does not incorporate the material nature of production and consumption activities (the external flows portrayed in Figure 1 circulating in a clockwise direction). This only actually happens whenever quantifying the scale of these flows (prices multiplied by the quantities produced or consumed over a certain period of time).

Nevertheless, the fact that the model does not explicitly recognise the real nature of these flows does not mean that they remain unaffected by their material nature and, correspondingly, the physical laws of nature. With scarcity a fact, for this not to interfere in the balanced functioning of the economy as described by the model in section 3, the following conditions need meeting: 1) all the inputs have to be fully converted into outputs; thus, with zero waste; and all the outputs have to be destroyed in the process of final consumption; 2) all the relevant natural resources need to be privately appropriated through the attribution of ownership rights and these rights need to be traded in competitive markets (Ayres and Kneese 1969). However, neither of these conditions actually exist in reality; nor is material susceptible to destruction (1st law of thermodynamics); nor is it possible to attribute property rights for all natural resources; nor even is it feasible to guarantee the competitive functioning of the markets for transacting ownership rights. Hence, the perpetual and balanced circular functioning of orthodox economists is no longer perpetually balanced due to the disruption brought about by anthropogenic overexploitation in the biosphere. One of the major contributions of Environmental Economics and Ecological Economics has been precisely the recognition of a physical economic frontier described in the circular model of exchange value flows. This recognition became possible when the orthodox paradigm based on the analysis of the economy as an isolated system underwent replacement by a new paradigm that approaches the economy as a living and open system integrated into another system, which is itself closed – the biosphere; therefore finally recognising the dependence of the economy on the real world and correspondingly subject to physical limitations and the physical laws of matter and energy (Ayres and Kneese 1969; Daily 1996).

The current concept of the CE precisely includes: the physical interdependence between the economy and the environment; the introduction of a physical limitation that reflects the scarcity and irreversible depletion of natural resources whenever subject to economic overexploitation; and the socioeconomic risks associated with this situation (section 2). Thus, the main objective is the reduction of waste across the extent of the chains of production and consumption while simultaneously guaranteeing the employability of the factor of labour and the sustainable creation of wealth. In order to achieve these objectives, the suggestion is for industrial economies to be redesigned according to a logic of *flows of materials* that circulate in circles (in cycles) among the different production and consumption activities as if the entire Industrial Economy functions as a living system subject to the natural physical laws of material and energy conservation – the thermodynamic laws for the conservation of mass/energy – according to which, in the words of Lavoisier, “in Nature, nothing gets created, nothing gets lost, everything gets transformed.” Furthermore, this constitutes the guiding principle behind the EMF definition of the CE.

The new paradigm: the relationship between economics and the environment

In the orthodox economic paradigm, the economic system is an isolated system that does not recognise the existence of any external limitations; in the EMF CE, the economic system (Industrial Economy) becomes an open system integrated into the environmental system. In the circular economic model of monetary flows, the economy knows no boundaries; there are however physical limitations in the CE. The circular flows in the model of orthodox economists derive from the exchange values defined by markets and measured in currencies; the CE flows however are real and measured in physical units (kilos, number of …, joules, kilometres, litres, *etcetera*). In summary: the circular economic model incorporates monetary flows that circulate eternally in closed circuits and may expand without limitations; the CE reflects the flows of materials in circulation *that are not eternal* because of the physical laws for the conservation of mass-energy. The current CE thus encapsulates a paradigm[29] that theoretically differs from the CE of orthodox economists.

Figure 3 presents a diagram displaying the Economy-Environment Interdependence[30] described according to this new paradigm. The line segments represent the flows of materials circulating among the system’s components and with the arrows indicating the direction of circulation. The large rectangle defined by the line in bold and that contains the economic system (represented by the rectangles for Production – Companies and Final Consumption – Households), depicts the *Biosphere* (the *Environment* – the set of all ecosystems on the Earth functioning as an integrated system made up of every biotic and abiotic element and process). The line defining the exterior rectangle represent the Atmosphere that establishes the frontier or boundary for the Biosphere; beyond which lies the Universe. Solar radiation penetrates the Biosphere through the Atmosphere to guarantee the existence of life on Earth and the survival of its ecosystems. An *ecosystem* is an integrated set within a determined spatial unit, made up of living organisms and the physical environment in which they live and their respective mutual interdependencies (Gilpin 1992). Each ecosystem includes both *abiotic* and *biotic* components (Tansley 1935). The former includes physical and chemical components (*e.g.* solar light, solar radiation, heat, humidity, rainfall, nutrients) that sustain the functioning of the ecosystems. The latter include the living beings divided into *autotrophs* that produce their own foodstuffs through means of photosynthesis and chemosynthesis and the *heterotrophs* that do not have this capacity to produce their own matter for consumption: either they consume that produced by other biotic members of the ecosystem (*e.g.* herbivores and carnivores) or they obtain nutrients from dead and decomposing organisms (*e.g.* fungi and bacteria).

[29] Daly and Farley (2004) defend the potential for the need to advance with an alteration in the theoretical paradigm, after Kuhn (Kuhn, T. 1962. *The Structure of the Paradigm Revolutions*, University of Chicago Press: Chicago), or a change in the *pre-analytical vision* of Schumpeter (Schumpeter, J. 1954. *History of Economic Analysis*, Oxford University Press: New York).

[30] The interdependence diagrams interlinking the economic and the environment may be found in any Environmental Economics or Ecological Economics textbook. This is our own highly simplified representation based on the allegory of the “space ship” put forward by Boulding (1966) in which the economic system is contained within the Environmental system, which establishes its borders. Other diagrams depict the economy as separated from the environment but interconnected through the flow of materials. We adopt the former because we consider it more appropriate to the objectives here. The diagram also stems from the flow diagrams published by Pearce and Turner 1990, Callan and Thomas 2000 and Perman *et al*. 2003. For a more extensive description of the economy-environment interdependence, suggestions would, for example, include Common, M. 1995. Sustainability and Policy: Limits to Economics. Cambridge University Press: Melbourne.

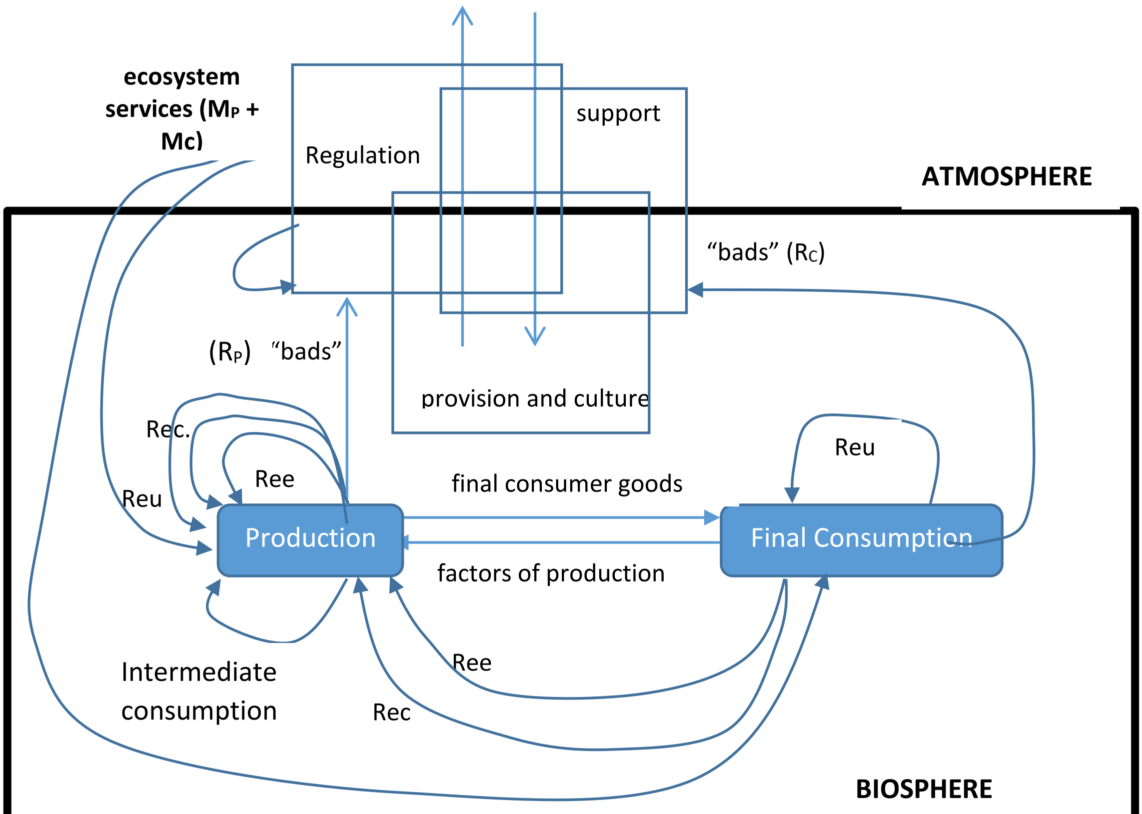

Figure 3 Model of Economic-Environment Interdependence (adapted from Perman *et al*. 2003)

The biotic and abiotic components are interconnected through the *flows of energy* and *nutrients* that extend throughout every ecosystem. In thermodynamic terms, the ecosystems are *open* systems as they continually exchange energy and material, both within and among themselves and with their surrounding environment. Their healthy functioning guarantees the production of a set of services (ecosystem services[31]) with low entropy levels (Georgescu-Roegen 1986) produced through their environmental functions. These services are depicted in Figure 3 by the three overlapping squares that represent the environmental functions guaranteed by the flows of energy entering and leaving the Biosphere (represented by the two vertical arrows crossing the squares). These services are appropriated (extracted or used) by the economic sector and generate different benefits contributing towards the creation of wealth and changes to the social wellbeing (Burkhard *et al.* 2010; Costanza *et al.* 1997). These benefits may, in turn, be grouped into four categories (Figure 3 conveys these through the four arrows that issue out of one of the squares: *provision of products* (wild foodstuffs, raw materials, medicinal and ornamental plants, biomass, air, solar radiation, water and genetic resources) and *cultural goods* (the cultural, educational and spiritual benefits associated with utilisation of the Environment through the final consumption of *curatorial goods* such as books, films, photographs, *etcetera*, experiences of recreation, education, research and therapy); *regulation* (decomposition of wastes and detoxication, carbon sequestration, control of pests and plagues, air and water purification, protection from extreme nature phenomena such as floods, cyclones and landfalls); and *life support systems* of ecosystems (nutrient cycles,

[31] The ecosystem systems are therefore defined as the conditions, processes and components of the natural environment that provide tangible and intangible benefits that sustain and satisfy the material, psychological and spiritual human needs (Daily 1997).

primary production, soil production, formation of habitats, pollenating, photosynthesis, chemosynthesis, *etcetera*) (TEEB 2010).

In the material flows model, both the Biosphere and the Economy become thermodynamic systems and, as such, subject to the respective thermodynamic laws (Daly and Farley 2004; Perman *et al* 2003; Callan and Thomas 2000; Pearce and Turner 1990; Daily, H. E. 1985; Boulding 1966; Georgescu-Roman 1986; Ayres and Kneese 1969; Soddy 1920). The first law states that in *isolated* systems*,* the quantities both of energy[32] and of matter (Georgescu-Roegen 1986) remain at 100%: nothing gets destroyed and nothing gets created anew; only the respective structures and physical states undergo alterations. Should we apply this law of physics to economic-environmental interactions, we are effectively affirming that whatever the means by which we extract the natural resources and irrespective of the quantities extracted, the same quantity shall always return to the environment (Pearce and Turner 1990) but in different physical states and temporal periods. The second law refers to the quality of the energy and matter existing in *isolated* systems: whenever energy or matter change their form, this raises the entropy of a system as there is the dispersion of energy throughout the process of transformation and, therefore, wastage of matter. These losses in energy and matter hinder the full reversibility of the energy transformation processes; hence, raising "disorder" in the system (*e.g.* a warm liquid cools spontaneously but the inverse remains impossible; in the act of a vehicle braking, there is a transformation in the kinetic energy into heat that then dissipates into the environment even while the inversion of this transformation is also impossible; in the environment, the production of salt results from the crystallisation of the minerals contained in seawater and their evaporation but it is impossible to reverse this process; in extractive industries, copper gets extracted from chalcopyrite to manufacture cables even though it is impossible to reconstitute the chalcopyrite from the copper used in cable manufacture with the burning of fossil fuels representing another irreversible process). The processes of converting thermal energy into mechanical energy are inefficient due to the loss of energy in the conversion process. Furthermore, the energy dissipated during such processes cannot be recovered in order to produce additional work. The *entropy* stems from measuring this dissipated energy that is not susceptible to recovery and the production of additional work. In sum, the second law means that whenever transforming something, there is always the dissipation and loss of energy due to the failure to fully and integrally apply it as work.

The physical laws of thermodynamics refer to *isolated* systems. However, the environment is a *closed* but not *isolated* living system. From the outset, there are exchanges of energy between this and the exterior – the universe – through the importing of energy inputs in the form of solar radiation and the export of the heat generated by the living and non-living systems of the planet (these energy exchanges are depicted in figure 3 by the two vertical arrows that span the three overlying squares). The equilibrium between these inputs and outputs determines the planet's climate. In turn, the economic system is *open* and enables the exchange of matter and energy with the environment. Given this, the level of entropy generated by the two systems should decline and not rise as neither system is isolated as those approached by the laws of thermodynamics. However, should the entropy in the two systems decrease, the second law would become irrelevant when applied to living systems – including the economy - (Perman *et al.* 2003). Nevertheless, matter (which is essentially energy) is consumed by the economic system in a fairly entropic fashion (Pearce and Turner 1990): the matter gets degraded and the energy dissipates over the course of their extraction, processing,

[32] In simple terms, in Physics, *energy* is a material characteristic and refers to the potential for carrying out work or providing heat. Work is undertaken whenever the energy alters the physical or chemical structure or when displaced. The energy may be transferred from one system to another through work (mechanical energy) and heat (thermal energy). According to the laws of thermodynamics, energy is a constant, neither getting destroyed nor created and only altering its structure.

consumption and reprocessing by the economic system (Georgescu-Roegen 1986). When anthropogenic activities extract energy from the environment in the form of natural resources, subsequently transforming them into other energy forms of worth to human beings (fuels, foodstuffs, raw materials), they are therefore extracting *low entropy* energy to transform this into *high entropy* energy. Whenever such transformation processes become intense and continuous, they may exceed the capacity for the regeneration of the environmental system that shall then enter into imbalance which, in turn, deepens the entropy already existing within its scope (Georgescu-Roegen 1986). In the economic system, entropy emerges in the form of *non-recyclable waste* or otherwise difficult to recycle or reuse (*e.g.* not all car components are recyclable; the plastics are only recyclable following extremely high investment costs (and with doubtful levels of efficiency) that the decision to do so would be economically and socially absurd; the batteries are not recyclable nor are all the toxic effluents recoverable or neutralised) and the energy either dissipated or irreversibly lost (*e.g.* whenever fossil fuels are burned, they disappear as such and so are unable to be restored to the environment; the extraction of natural gas produces a sub-product, the gas flare, which may or may not be put to use; during their functioning, boilers lose heat that may or may not be recovered).

Returning to the description of the model set out in Figure 3, the economic system is contained in the Biosphere and is, therefore, physically limited meaning that it is not susceptible to boundless and infinite growth contrary to that put forward by neoclassical economists. Production and consumption draw on ecosystems in order to benefit their services. Production extracts low entropy environmental resources – *primary inputs* (minerals, rocks, liquids, gases, soils, wind) - and transforms them into products with high levels of entropy (secondary energy, foodstuffs, raw materials) – *outputs* – that shall be sold to the respective productive sectors as *inputs* (intermediate consumption) or sold to households (final consumption). We should note how in this new vision of the functioning of the economy, production does not *create* anything but rather only *transforms* energy (the matter) extracted from the biosphere in other energy forms that are then applied to obtain new usages (first law of thermodynamics[33]). These environmental resources also serve directly for the purposes of households and their final consumption or self-production (*e.g.* foodstuffs, produce of warmth, spiritual wellbeing, recreation, culture, raw material). Economically, all of the goods traded in the market are desired by the economic actors to the extent that they are useful to them. In addition, others are produced that are undesired but inherently interlinked with the former: these constitute the sub-products that may take the form of solids (wastes, garbage), liquids (effluents) and gases (*e.g.* gas flares; pollutants). Part of these sub-products might be reintegrated into the production and consumption as desirable goods through *recycling* (Rec), *reutilisation* (Reu), *repair* or *readaptation* (Ree) and/or *remanufacture* (Rem) (in Figure 3, these flows are depicted by the circular arrows that emerge from the Production rectangle). The remainder as discharged directly or indirectly into the biosphere as liquid effluents, gases and garbage (arrow of the "bads" coming out of Production), where they are stored, decomposed and detoxicated by the natural life support systems, and finally reintegrated into the Biosphere in the form of natural capital. Households (consumers) purchase the products supplied by the

[33] It is interesting to recall how many conventional economists recognise the thermodynamic nature of the productive processes and the physical dimensions to production and consumption. Take, for example, what Alfred Marshall stated on this matter: "Man cannot create material things - his efforts and sacrifices result in changing the form or arrangement of matter to adapt it better for the satisfaction of his wants – as his production of material products is really nothing more than a rearrangement of matter which gives it new utilities, so his consumption of them is nothing more than a disarrangement of matter which diminishes its utilities (*in* Marshall, A.. 1961. *Principles of Economics*, 9th edition. New York (original edition 1920): 63-64, quoted by Daly 2006). Nevertheless, this only recognises interactions according to the logic of the first law of thermodynamics and does not go into further detail as regards the logic of the second law which is exactly the law imposing physical limitations to growth associated with the scarcity brought about by the advancing entropy of the environmental system.

producers (final consumption arrow in Figure 3) and deploy environmental services to obtain the desired utility; after having extracted this, they throw away the materials. The discarded materials may end up either disposed of in the biosphere as garbage ("bads" arrow coming out of the Household rectangle) where they are transformed and assimilated by the life support environmental services; or they may return into the sphere of Production through recycling (Ree), remanufacturing or readaptation (Rec); or they may alternatively be reutilised by the Households (Reu). In exchange for the products supplied by producers, Households provide them with factors of production (Labour – human capital - and Savings – investment) that are then applied in perpetuity in the productive economic circuit.

Whenever economists wish to refer to the laws of thermodynamics or the conservation of mass as applied to Economics, they apply the principle of mass balance, figuratively represented by the material flow model in figure 3 and formally described as equality MP + MC = Rp + Rc: hence, the quantity of mass or of natural resources (material, energy, services) extracted from the environment is equal to the quantity of material and energy disposed of into the system, therefore, in a more specific format, Rp + Rc = M = Bens + R – Reu – Ree – Rec. Seminal and formal descriptions of the application of the principle of the conservation of mass for the functioning of economies are provided in Ayres and Kneese (1969), Kneese *et al*. (1970) and Perman *et al.* (2003).

The growth of entropy within the scope of ecosystems caused by anthropogenic activities directly relates to the interactive material interdependence between the Biosphere and Economic systems. The literature recognises the economist Georgescu-Roegen for having pioneered the building of the bridge between the physical laws of thermodynamics, the functioning of the economy and the growth in entropy in his seminal work *The Entropy Law and the Economic Prospect in Process* first published in 1986[34]. Anthropogenic activities dissipate energy and waste materials that are both disposed of in the biosphere. Some of this energy and material may be swiftly assimilated by the biosphere. Another part will only achieve this according to temporal timeframes that become absurd for human consideration. Another proportion will only ever be reintegrated into Biosphere when having been subject to prior recycling or restructuring in the production system, which will only take place when making economic sense (thus, generating value) and when also not excessively demanding in terms of new low entropy resources. Therefore, entropic intensity becomes dependent on the level of waste in the economic system (2nd law of Georgescu-Roegen *op. cit*). The greater the intensity of extraction - or usage – of low entropy natural resources (M), the more intense the flows of Residues discharged into the Environment (Rc and R_P) and the greater the level of entropy. As the maintenance of low entropy energy flows constitutes one of the vital conditions for maintaining the sustainability and resilience of natural ecosystems – which enables them to ensure the maintenance of all their natural functions – their reduction places the balance of the biosphere at risk. In turn, this heightens the risk of the occurrence of imbalances in the economic system. It is due to this rising entropy that some ecological economists (*e.g.* Daily 1985; Georgescu-Roegen 1986; Soddy 1920) demonstrate that it is impossible to guarantee the perpetuity of the circular model of materials based on the principle of mass balance as is described in Figure 3. What this effectively means is that it becomes impossible to affirm that the cycles of material flows defined within the framework of the current CE are continuous and, therefore, perpetual over the long term. In keeping with the law of thermodynamics, even when able to reduce the speed of circulation and the volume of the cycles, there shall always be the dissipation of energy and the waste of material that shall always be disposed of in the biosphere; which, in a final instance and over the long term,

[34] We would highlight how Daily (1985) states that Soddy was the precursor in this relationship. In fact, reading the work by Soddy (1920) almost entirely recalls the work of Georgescu-Roegen *op. cit; however, this does not make any reference to the work of the former.*

means the forecasting of the continuous growth in systemic entropy and the imbalances in the systems[35]. The material flow model is thus not a *continuous driver* because of the laws of thermodynamics.

The CE, linear economy and the model of material balance

In the literature on the CE, the *linear economy* refers to the model of material flows, applied to the workings of the economic system as if this were an isolated system and, therefore, without any wastage, recycling or disposal (Murray *et al*. 2017). The *linear economy* designation, while not new (Daly and Farley 2004; Pearce and Turner 1990; Boulding 1966), became popularised in the literature on the CE from 2000 onwards (Murray *et al.* 20017) with the objective of highlighting the difference in relation to the idea of *circularity*. The linear economy is an economic model for material and energy flows that head only in one direction, hence along a single path (Figure 4).

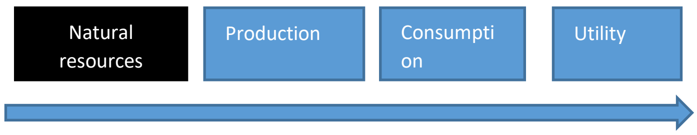

Figure 4 Linear model of material flows (*throughput*) (adapted from Pearce and Turner 1990)

This one-way direction begins with the extraction of the natural resources and ends with the usage of the products produced by these resources by consumers, who thereby obtain utility or wellbeing: “If we ignore the environment then the economy appears to be a linear system” (Pearce and Turner 1990, p. 35). This differs from the economic model of value flows described in section 3 on two fundamental points. This refers to flows measured in exchange values (currency) and with the linear encapsulating the material flows measured in physical units (the “throughput”). The flow value model is circular and not unidirectional as in the linear model. The circularity of the former refers to the creation of value and its redistribution, which reflect the leading objective of the circular economic model. While the linearity of the second refers to the material flows of resources extracted from the biosphere that are then deployed in the productive process in order to produce the goods that consumers then use for the extraction of utility. Both share in common their non-recognition of Economy – Environment interactions.

The linear or throughput model transforms into the circular model of material and energy when: explicitly incorporating the environmental system; recognising (and quantifying) the wastage of material and energy generated by the extraction, transport, transformation and consumption processes; and recognising (and quantifying) the wastage disposed of, thus, the Residues (Figure 5). One part of these Residues returns to Production and to Consumption (recycling, reutilisation, *etcetera*) thereby closing the cycle of flows between the Environment and the Economy; another proportion is disposed of in the Environment (Pearce and Turner 1990). The greater the speed and value of the flows of waste and disposal, the greater the level of entropy and the risk of imbalances in the Economic and Environmental systems. This is the model underpinning the CE conception proposed by the EMF. This differs from the circular model in section 3 to the extent that this explicitly recognises the interactions ongoing between the Environment and the Economy and because the inter-systemic flows are measured in physical units and not exchange values. This also differs from the economic model

[35] This exact same rationale over the inexorable nature of the advance of systemic entropy caused by anthropogenic activities led many economists to return to the idea of zero growth (*degrowth*) and today especially defended among ecological economists.

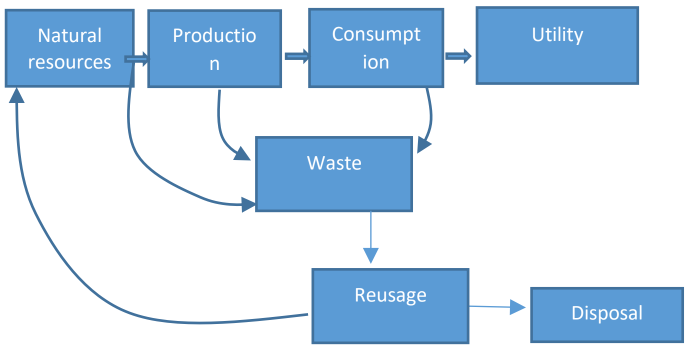

Figure 5 Circular model of material flows (adapted from Pearce and Turner 1990)

of circular flows of value in how the circular flows of material are not 100% circular due to the inevitably rising entropy materialised in the constant accumulation of waste in the biosphere; even while the exchange value flows in the circular economic model are in fact both circular and eternal. The circularity of the CE in the current context is not a *continuous driver* as the material flows are subject to the thermodynamic laws of physics and, as such, to entropy. However, in the economics CE model, the circular flow is a *continuous driver* because, as a flow of exchange values, this is not subject to the laws of physics. As the economists do not recognise the role of the environment in the functioning of the economies, there are no materials requiring consideration and the flow of exchange values may also be eternal in keeping with its self-sustaining nature. The model of value flows is an accountancy construction and, as such, is by definition always in balance (Daily, 1985). The national accounts, the state budget or company balance sheets that they produce are also similarly always in balance. However, this is not any real balance in the sense of being material and physical: this is an accountancy equilibrium and, therefore, intangible (in opposition to a material, physical balance).

Based on that hitherto discussed, the following conclusion clearly emerges: the description of the functioning of an economy – whether industrial or otherwise – as if an organism or a system built up out of its components mutually interconnected by flows of something that flows between them in circles that then constitute eternal cycles, is not any new idea. In section 3, we demonstrated that the term *circular* was already in use in the 18th century to explain the workings of the economy. Orthodox economists have continued to deploy the paradigm of the circular model of value flows in macroeconomic analysis of national accountancy systems and company accounting. The idea of material (energy) circularly flowing between components of the economy and of the environment, constituting cycles in which the outputs of some are the inputs for others, as well as the description of the material dependence existing between the economy and the environment are also not at all new. For example, R.W. Hofman, the first President of the Royal Society of Chemistry, back in 1848, was affirming how the ideal operation of a chemical products factory would be one in which the concept of waste disappeared and was instead replaced by the concept of product (Murray *et al.* 2017, quoting Lancaster, M. 2002. Principles of Sustainable and Green Chemistry. In Clark, J. and Macquarrie, D. (eds) 2002. *Handbook of Green Chemistry and Technology*, p. 10-27, Blackwell: Oxford). In 1920, the chemist Soddy[36] emphatically criticised the circular model of

[36] Daily, one of the core founders of Ecological Economics, deems Soddy the precursor of the works of Boulding and Georgescu-Roegen, even while the latter does not make any reference to the former (Daily 1996).

value flows in questioning the economic explanation of its functioning as if some kind of machine of perpetual motion (Soddy 1920). The classical economists then came in for lively criticism for having ignored both the relationship between Economics and the environment and the effects of entropy on the economic and environmental equilibria. In 1966, Boulding declared that the ideal workings of any economy would have to incorporate the logic of a "cyclical ecological system" (Boulding *op. cit.* p. 8). Smith (1967) would have been the first to apply the model of mass equilibrium to the activities of disposing and treating waste materials (Ayres and Kneese 1969). Ayres and Kneese (1969) describe the material relationship between the economy and the environment and formally frame this in the mass equilibrium model described above. Kneese *et al*. (1970) describe the conservation of mass principle as applied to Economics. Stahel and Reday-Mulvey (1976) termed the concepts of "closed cycle economy" (Murray *et al*. 2017) and "cradle-to-cradle". Both Georgescu-Roegen (1986) and Daily (1985) describe the effects of entropy and warn of the physical impossibility of the model of circular material flows enjoying perpetual motion. Frosch and Gallopoulos (1989) advocate for the reorganisation of industry according to the logic of industrial ecosystems through analogy with living systems and introduce the concept of industrial eco-parks where materials get internally recycled and where energy becomes the only input with its origins in the Environment. Pearce and Turner (1990) describe the model of material balance and explicitly and for the first time designate the *circular economy*.

Bringing together all the analysis thus far undertaken, we believe we are now positioned to respond to the questions formulated at the outset and thereby achieve the objective we defined. The first conclusion is on the relationship (whenever existing) between the CE of orthodox economists, and the CE described by the material flow models of the environmental and ecological economists and currently much referenced. The former explain the workings of the economy through a circular model of flows of exchange values while the latter deploy an explanation involving a circular model of flows of materials and energy. The CE of economists refers to an isolated economy that contains the environment and does not recognise the existence of any dependent relationship as regards the latter. This model is effectively perpetually circular as there is no recognition of any existence of any physical limitations on economic growth and correspondingly based on intangible and immaterial accountancy flows, eternally balanced by their inherent definition. The CE of environmental and ecological economists and the authors of the current CE concept instead refer to an economy as an open system, integrated into the environmental system that is closed and, as such, recognising the presence of boundaries associated with the physical characteristics of the matter subject to the physical laws of thermodynamics. However, this is not effectively circular on account of the entropy generated by the continuous extraction of low entropy materials from the environment and the disposal of high entropy materials into that same environment. Therefore, contrary to what the current CE concept defends, the CE always holds an impact on the environment even when implementing actions able to reduce the speed and volume of the flows of low and high entropy materials. Hence, the designations here are the same linguistically; they always refer to systems that function according to a circular logic of flows, but they apply to different things. The paradigm of the CE of economists is completely different from the paradigm of current CE and the CE of environmental and ecological economists. CE is therefore a polysemic concept.

The second conclusion regards the question as to whether or not it is novel and innovative to describe the economy in terms of circles and cycles. This point has already received ample discussion above and the response is no.

The third conclusion approaches the putative newness of the designation *CE*. In linguistic terms, this is not a 21st century innovation either for orthodox economic theory or for environmental or ecological economics as also demonstrated above. Correspondingly, the designation CE, in its current meaning, does not represent anything new. Since the beginning of the 20th century, there have been descriptions and models proposed to explain the integral functioning of the economy and the environment based on circular material flows. Nevertheless, the CE designation is not explicitly referenced. It would appear that only in the 1990s, when Pearce and Turner describe the interactive behaviours between the economy and the environment through deploying a model of material and energy flows that the CE was first specifically referenced.

Indeed, what in all this is new? There is contemporary literature affirming that the CE is a new concept. There are even authors stating that this is a Chinese concept (Liu *et al*. 2009; Yuan *et al*. 2006). Our analysis enables such affirmations to be refuted. From the conceptual and formal point of view, the current CE concept may above all trace its roots back to the Economics-Environment models based on the principle of the balance of materials (or of mass) and the physical laws of thermodynamics. In the 18th century, some physicians were already criticising economists for not duly recognising the role of the biosphere in the functioning of the economy as well as overlooking the real flows to overly concentrate on flows of exchange values. Furthermore, in addition to these conceptual and methodological roots, the current CE concept also stems from other theories formulated in the 20th century (Wautelet 2018; Murfay *et al.* 2017) including: Industrial Ecology and Industrial Metabolism (Ayres 1994) Industrial Ecology (Erkman 1997); Cradle-to-Cradle C2C (Braungart and McDonough 2002); Performance Economy (Stahel 2010); Blue Economy (Pauli 2010); and Biomimicry (Benyus 1997). It is through these that we may explain how the CE principles – as defined by the EMF – may be applied in practice in order to advance with the reorganisation of the industrial economy, thus, the production and consumption sectors. What is effectively new in the current CE arises from the recognition of the CE principles on behalf of the business and financial world in conjunction with national and regional governments that have finally grasped and recognised how ignorance about the physical limitations to economic growth result in the overexploitation of natural resources, the deterioration of ecosystems, increases in entropy and, finally, to worsening economic, environmental and social risks.

5. Conclusion

This study strove to answer the following questions: Is the current CE concept similar to those held by neoclassical orthodox economics and by environmental and ecological economics? What relationship exists (if any) between the linear economy referred to in articles on this "modern" CE and the CE concept taught to any Economics student in their first classes on economic theory? We have subsequently demonstrated how there are only three shared points to the concepts held. The first point derives from the word "circular"; all these designations apply the same rationale based on flows that circulate in a circle to explain the relationship between production and consumption. The second shared point arises from how all these designations refer to the relationship between the systems of production and consumption as forming the core of any economy. Finally, the third point stems from how all these designations deploy the same linguistic concept – the CE. That brings the similarities to an end.

We also sought to convey how their respective theoretical paradigms differ from each other, that the objectives of their core models are also different and that the nature of the flows that they refer to are radically distinct from each other. We additionally set out to demonstrate how the current CE concept is not a new theoretical construct.

The findings result from reviewing the literature produced on the CE and the CE "concept" between 1960 and 2020. The discussion about the meaning, origins and innovativeness of the

CE took into account the conceptual frameworks of History of Economic Thought, Macroeconomics, Environmental Economics and Ecological Economics. We chose the CE definition proposed by EMF due to the lack of consensus prevailing about the CE's meaning and as this is the definition most cited and most widely considered in the literature.

The first conclusion approaches the relationship (if any) between the CE of the orthodox economists and that referred to and described in the flow models of the environmental and ecological economists and that currently greatly debated. The former explains the workings of the economy through a circular model of exchange value flows while the latter explain this through a circular model of flows of materials and energy. The CE of orthodox economists encapsulates an isolated economy that contains the environment and does not recognise the existence of any dependence in this relationship. This model is effectively perpetually circular as there is no scope for any physical limitations on economic growth as it is grounded on accountancy flows, intangible and immaterial, and in eternal equilibrium due to their own definition. The CE of environmental and ecological economists and the authors of the current CE concept perceive the economy as an open system integrated into the environmental system that is closed and, as such, recognising the existence of limitations associated with the physical characteristics subject to the physical laws of thermodynamics. Furthermore, this approach is not effectively circular due to the entropy generated by the continuous extraction of low entropy material from the environment and the discharge of high entropy material into that same environment. Hence, contrary to what the current CE concept defends, the CE always has an impact on the environment even when implementing actions that reduce the speed and volume of the flows of low entropy and high entropy materials. Therefore, the designations here are the same linguistically; they always refer to systems that function according to a circular logic of flows, but they apply to different things. The paradigm of the CE of economists is completely different from the paradigm of current CE and the CE of environmental and ecological economists. CE is therefore a polysemic concept.

The second conclusion answers the question as regards the newness of describing the functioning of the economy in circles or cycles. The response is no.

The third conclusion spans the putative newness of the *CE* designation. Linguistically, the term is not new either to the 21st century or to orthodox economic theory or to environmental or ecological economics as duly demonstrated. For this same reason, the current meaning attributed to the CE is also neither new nor innovative. Ever since the beginning of the 20th century there have been descriptions and models proposed for the integrated functioning of the economy based on circular flows of materials. Nevertheless – to the best of our knowledge – the CE designation is not explicitly applied in these designations. It would appear that the term only emerged in the 1990s when Pearce and Turner described the interactive behaviours of the economy and the environment through recourse to a model of material and energy flows that they explicitly designated as the CE.

Indeed, just what then is new in all of this? What is effectively new about the current CE proposition is the recognition received of its principles across the corporate and financial sectors and among national and regional governments that have finally grasped and recognised how ignorance over the physical limitations to economic growth results in the overexploitation of natural resources, in the deterioration of ecosystems brought about by the rise in entropy and the corresponding economic risks.

As we draw this study to a close, another question emerges. Just how might we "marry" the CE of the value flow model and the current CE? The former is founded on the orthodox paradigm that underpins national and corporate accountancy systems and is taught to any and all economics students. The second belongs to a different paradigm based on the recognition of real flows and dependence on the environment and advocated by environmental and ecological economists alike. However, the latter belong to scientific fields that, despite the preponderant profile gained from the 1960s onwards off the back of environmental disasters causing enormous economic and social harm, still remain marginal areas to studies on Economics and on academic curricula. In order to "marry" this pair, there is a need for orthodox economics to abandon the conventional paradigm that considers the economy to be an isolated system functioning as if some machine of perpetual motion and that is always in balance simply because this equilibrium embraces an accountancy assumption and is therefore artificial and unreal. Thus, the conventional paradigm requires replacing by a new paradigm that recognises and internalizes the economy-environment interactions and their flows of materials and energy. Should such come to happen, the current national and corporate accountancy system would also need replacing with that called Green Accounting.

In academic terms, this change is very far from taking place. The conventional economic paradigm remains in effect and the new paradigm remains marginal and poorly understood. However, the business community and government now do perceive the economic, social, political and environmental risks from continuing along the path of eternal economic growth measured by exchange value and ignoring (disregarding) the impacts on ecosystems and the reverse effects. Business management has understood that the best strategy for maximising profit is combatting waste throughout every stage of the business model. Governments perceive that the long term environmental, social and political consequences of continuing with the current system of economic growth based on the linear economy may prove catastrophic for both societies and civilisations. Furthermore, the population in general is increasingly aware of environmental questions and the effects of the current model of economic growth. The new environmental, economic and social circumstances may serve as the trigger for academia and economists to understand the need and the importance of beginning to seriously work on changing the theoretical paradigm. This change becomes an imperative when recalling how the CE is not only about applications by individual companies developing new businesses and continuing to maximise profits. The CE conveys a need to implement a new strategy for the organisation of economies and their productive sectors; for the relationship between production and consumption; for a new role for consumers; and while also proposing conceptual alterations to the theoretical framework of orthodox economics. In effective terms, implementing the CE in accordance with its definition by EMF suggests a revolution not only in terms of economic organisation but also in the objectives and behaviours of all economic actors and in the theoretical paradigm for economic growth.

Deploying the conventional model of circular flows of exchange values to implement this revolution constitutes, in the words of Daily (Daily 1985), a fallacy to the extent that this would be confusing an abstract constructed for a specific purpose (describing the process of creating monetary or exchange value and the functioning of economies) with reality (the physical interdependence between the economy and ecosystems). This author reaches further in his criticism of the orthodox growth model and forecasts that the destiny of this economic growth would end up in a stationary position. The rationale behind this prediction stems from the coexistence of two neoclassical theoretical ideas that Daly perceives as mutually contradictory. The first idea states that the guarantee of growth rates remaining constant over the course of time – and, therefore, being sustainable – may only be obtained at the cost of growth in the capital stock – especially the built stock - and the intensification of the earnings flows thereby generated, which would then intensify the rate of transfer of low entropy materials to high entropy materials. The second idea maintains that, as the guarantee of sustainable growth rates involves increasing the transfer rates of low entropy to high entropy materials, this situation will end up in bringing about generic scarcity that rises in keeping with the growth in wealth. This situation of scarcity may impact just as much on the supply of inputs for upstream production of economic sectors (scarcity of natural resources), such as the quality of collection and treatment services for the production and consumption of waste materials, to downstream issues (limitations on the capacity of the environment to assimilate the used materials and energies). In the opinion of Daily, these two ideas reflect an irresolvable contradiction in neoclassical theory that may only be overcome through the adoption of a new growth paradigm. Hence, the author proposes that a stationary economic state may be a credible solution for overcoming the aforementioned contradiction inherent to the dominant growth paradigm. His new paradigm assumes the characteristics of a paradigm as set down by Kuhn[37].

Furthermore, any implementation of the CE principles suggests the need to incentivise the networking behaviours of companies and the productive sectors and the respective planning of their operations. Hence, the CE emerges as a revolution that once again places the state at the pinnacle of strategic decisions. The state is the stakeholder in the best position whether to define strategies based on the CE principles or to endow the infrastructural conditions so that actors may then take their own individual decisions but within a structured and networked context.

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[37] According to the philosopher Thomas Kuhn, the progress of science always happens whenever the prevailing paradigm is no longer able to provide solutions or explanations to the questions arising from the observations of researchers (Maine University 2012).

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