Write circular economy, read economy's circularity. How to avoid going in circles

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Abstract
Enthusiasm for the Circular Economy (CE) is widespread and overwhelming. However, confusion around its meaning and purpose still pervades the scientific debate. Our study has two objectives. The first one is to increase the theoretical clarity and the scientific relevance of this debate. An important step forward in this direction is the idea of *economy's circularity*, which we introduce following a critical re-visitation of CE's notion. The second objective is to study the environmental effects of circularity. Our notion of *economy's circularity* is theoretically rooted in the materials-energy balance model, and points to the presence of circular matter and energy flows in the economy. A major strength of this definition is the conceptual separation of *circularity* (as an economy's feature) from the *strategies* (e.g. recovery, remanufacturing, reusing…) for its implementation. On one hand, this separation prompts the construction of a coherent framework, which helps shed light on the entire debate. On the other hand, it paves the way towards a novel methodology for studying any type of circularity effect. Circularity effects are indeed the effects of *circularity strategies*. Since strategies are constantly evolving, this approach delivers an immediate result. Circularity effects are unavoidably ambiguous. With reference to the effects on the environment, we provide evidence for this ambiguity by accurately selecting and reviewing studies on various circularity strategies. In a policy perspective, our findings seriously challenge the idea of implementing circularity for the sake of circularity. Indeed, using circularity as an environmental policy may prove quite a daunting task.

Keywords Circular economy · Economy's circularity · Environmental effects of circularity · Policy role of circularity

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1 Introduction

The ongoing debate on the Circular Economy (CE) is based on a rather unclear notion of CE (Haas et al. 2015), and it is quite inconclusive regarding its aims (Heshmati 2015). In this context, scientific research appears a priority in two main respects. On one hand, the debate appears to need more conceptual clarity and eventually higher scientific relevance. On the other hand, it would be important to disentangle more precisely the possible aims of the CE. With regard to the first issue, the main objective of the present paper is to reconceptualise the notion of CE in terms of *economy's circularity*. The definition we propose postulates *economy's circularity as a positive feature of the economy that consists in the presence of internal circular energy and matter flows*. The circularity of flows allows keeping matter and energy within the economy with the consequence of delaying their return to the environment. Notice that this feature is the core principle in the CE as well. Our notion of circularity however, differs from the concept of CE in three main respects. First, it is coherent with the materials-energy balance model of Ayres and Kneese (1969) and Kneese et al. (1970), and hence, it is compatible with the laws of thermodynamics. Second, it is simple and parsimonious. Third, it is independent from the instruments used for its implementation.[1]

With regard to the aims of the CE, the standing questions in the CE debate can be easily reformulated in terms of economy's circularity. The notion we propose has in fact three distinct interpretations, which differ for the discipline they refer to, but they are mutually related. Besides the thermodynamic one, which is the most comprehensive one and also the closest to our definition of circularity, there are one environmental and resource-related interpretation and one economic interpretation. Hence, our notion of circularity is compatible with ecological economics, environmental and resource economics, and standard economics. This means that it is the appropriate starting point for the analysis of any effect belonging to these three areas. While we maintain that research in *all* these areas is equally relevant considering the current state of the debate, we choose to focus on the environmental impacts of circularity. The question of the environmental potential of the CE is in fact highly controversial. Studies that include the CE among the "recent low-carbon development strategies" (Winans et al. 2017: 825) do actually coexist with studies (e.g. Andersen 2007; Allwood 2014; Potting et al. 2017) who argue for the possibility that the CE may be eventually harmful for the environment.

[1] Because of these three features, we deem the notion of "economy's circularity" theoretically preferable to the one of "circular economy". From a terminological point of view, conceptual consistency would subsequently require dismissing the term "circular economy". However, since we find this dismission nearly impossible at this point, we pragmatically accept the (terminologically) luckier term, yet with the caveats of the arguments put forward in this paper.

The notion of circularity, as we define it, implies a clear-cut separation between circularity (as a feature of the economy) and the instruments for its implementation (e.g. recycling, recovery, reuse…), which we call *circularity strategies*. This separation proves essential for both the objectives of this paper. As far as the definition of circularity is concerned, it allows removing an important source of confusion, which arises in the conceptualization of the CE. This difficulty is well illustrated in Kirchherr et al. (2017), who note that "[k]nowledge accumulation regarding the CE is difficult if scholar A conceptualizes the 'how-to' of CE as recycling, while scholar B considers the 'how-to' as reducing" (Kirchherr et al. 2017, p. 228). The separation of circularity from circularity strategies solves this problem, and at the same time, provides the notion of circularity with higher theoretical stability. The emergence of new strategies or their evolution over time may in fact occur while leaving the concept of circularity unaltered. With regard to the investigation of the effects of circularity, the separation of *circularity* from *circularity strategies* opens the way to a novel approach in this respect. If circularity strategies are the instruments for the implementation of circularity, then the effects of circularity coincide with the effects of the strategies.[2] Hence, studying the effects of circularity equates studying the effects of the strategies for its implementation.

In this paper, we adopt this novel approach to analyse the environmental implications of circularity. This method helps highlighting that circularity can be enhanced using (virtually infinite) combinations of strategies. Since strategies differ from one another, and they are usually associated with non-zero environmental costs, effects vary with the strategy and, within a given strategy, with the specific *circularity project* implemented. Hence, the environmental effects of circularity can be only quantified upon specification of the precise case of reference. This prompts the claim that they are theoretically ambiguous. We provide evidence for this theoretical ambiguity through a selection of studies, which we recover from two different strains of literature. Beside that on the CE, we screen the wider and (in some cases) older literature on circularity strategies (e.g. recycling, energy recovery from waste…). We find many papers that deal with the environmental effects of circularity, but only few of them provide a proper quantification of these effects. In this respect, the really relevant contributions are those that provide a comparison between the environmental effects of a specific circularity project and the effects of its non-circular (i.e. "dispose-and-produce-new") counterpart. For their own nature, however these studies are necessarily case-specific, and they are usually concerned with an incomplete set of effects.

The rest of the paper is organised as follows. Section 2 illustrates the main motivation for reconceptualising the notion of circular economy in terms of economy's circularity. Section 3 is devoted to this reconceptualization and to the development of a new theoretical framework for a first conceptual systematization of the overall

[2] Note that this equivalence does not contrast with the fact that higher circularity benefits from an overarching, systemic view. The realization of higher circularity in fact, passes in any case through a series of concrete projects with specific environmental effects.

CE debate. Section 4 provides literature-based evidence about the ambiguity of the environmental effects of circularity, and Sect. 5 concludes.

2 Motivation for reconceptualising the *circular economy*

This Section has the role of a *trait d'union* between the existing literature on the circular economy and this paper on economy's circularity. Its aim is to illustrate the main motivation for reconceptualising the notion of circular economy in terms of economy's circularity. To this purpose, it explores the large literature describing the essence and the aims of the circular economy. A major finding of this review is that there are more than a hundred competing definitions (and understandings) of CE, and most of them are scientifically weak. Winans et al. (2017, p. 826) for example, recognise that "the CE concept does not work for thermodynamics". Under these circumstances, it is not surprising that no consensus has been reached on the aims of the CE, which still range from a better environment to higher national security, including stronger economic growth, lower unemployment and higher resource efficiency. In the case of the EU Action Plan for the Circular Economy, for example, its main motivation is to "address […] sustainability" (Geissdoerfer et al. 2017, p. 758). However, nearly two years after the release of the Plan, the survey by Kirchherr et al. (2017) finds that the relationship between CE and sustainability is mostly ignored. Another survey (Geissdoerfer et al. 2017) finds that this relationship is "not made explicit in the literature" (Geissdoerfer et al. 2017, p. 757).[3]

Dealing with the existing definitions of CE is actually difficult for two reasons. One is that they are often vague and imprecise (Haas et al. 2015). The other is that their proponents usually fail to set them in relationship with the earlier ones, or to illustrate the reasons for their new conceptualisations. Hence, the literature contains a bunch of *similar* definitions, which are potentially all worth consideration, although not useful for a real progress in the debate. A number of surveys (e.g. Kirchherr et al. 2017; Winans et al. 2017; Ghisellini et al. 2016) are particularly useful in this regard, for they provide conceptual reviews of the existing CE understandings. Their main contribution is a sort of stylization regarding the "features" (Ghisellini et al. 2016, p. 11) or the "core principles" (Kirchherr et al. 2017, p. 223) and the "aims" (Kirchherr et al. 2017, p. 223) of the CE. Valuable as they are however, these studies allows learning about "the understanding of [the] concept" (Kirchherr et al. 2017, p. 222) of CE, something which is not equivalent to learning what the CE actually is. The work of Kirchherr et al. (2017) for example, provides more a stylized description of the CE concept rather than a scientific foundation of it. Although it is based on a statistically non-representative sample,[4] one important contribution of this study is a list of features, which in view of their frequency may

[3] This is a cause for concern (in policy perspective) and a motivation for further research in this area.

[4] The authors do state their "intention to develop a representative sample of CE definitions" (Kirchherr et al. 2017, p. 222), but they disaffirm such intention a few lines thereafter. They conclude that their sample is "at least *fairly representative* [italics in original]" (Kirchherr et al. 2017, p. 222).

be considered as the accepted characterization for the notion of CE. These surveys, together with other papers (e.g. Heshmati 2015; Bocken et al. 2016; Wysokińska 2016) are an important reference for us because they provide the motivation for introducing the notion of economy's circularity. Moreover (in Sect. 3.1), they constitute the benchmark for comparing this notion with the (stylized) one of CE.

Although the characterizing feature of the CE is the presence of circular flows (loops) of energy and matter within the economy, there are many definitions of CE that do not mention this feature explicitly. This is well documented in the survey by Kirchherr et al. (2017) who screen roughly hundred definitions and do not include flows' circularity among the "core principles […] of CE" (Kirchherr et al. 2017: 223). One of these definitions, which appears in many peer-reviewed studies is due to the Ellen MacArthur Foundation (EMF). It states that the CE is "an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models" EMF (2012: 7). According to "Geissdoerfer et al. (2017, p. 759) as well as Schut et al. (2015, p. 15) [this is] the most prominent circular economy definition" (Kirchherr et al. 2017, p. 226). In the same literature, however, there are also many contributions (e.g. Geng and Doberstein 2008; Webster 2015; Yuan et al. 2006; Bocken et al. 2016; Geissdoerfer et al. 2017), which do consider flow circularity as one of the main features of the CE.

Most of the authors who recognize the role of loops in the circular economy, further claim that these circles are *closed*.[5] Intuitively, this would indicate that energy or matter could remain in the economy forever. For energy, this claim is clearly nonsensical, because any energy transfer or transformation implies some energy loss, i.e. some energy dissipation into the environment (i.e. out of the economy). For matter, even if it were technically possible to maintain a given amount of matter in the economy indefinitely, this would probably result in unsustainable environmental and economic costs. In a simple economic perspective, the increasing marginal costs of maintaining a given type of material in the economy would unequivocally lead to the termination of such activity as soon as marginal costs exceed marginal benefits. Indeed, the fact that loops cannot be closed for physical reasons has been unequivocal at least since the work of Daly (1977) and Georgescu-Roegen (1971), and there are various authors (e.g. Andersen 2007; Fischer-Kowalski et al. 2011; Allwood, 2014; Rammelt and Crisp 2014; Ghisellini et al. 2016; Winans et al. 2017), who provide further (technical, economic…) reasons for this fact. However, despite its self-evidence, this point seems to fail constantly to obtain the status of accepted conclusion in the debate, and many authors keep fostering the "closing-the-loop" idea. For Geissdoerfer et al. (2017: 764) for example, "it seems clear to most authors that the Circular Economy is aiming at a closed loop" while Geng and Doberstein (2008: 231) believe that the CE is the "realization of [a] closed loop material flow in the

[5] These authors are for example, Mathews and Tan (2011), Wysokińska (2016), Sauvé et al. (2016), Geng and Doberstein (2008), Guo et al. (1997).

whole economic system". In Ghisellini et al. (2016), the authors manage at the same time to explain that closed loops are unrealizable, and to affirm that "The circular economy, […] helps optimize natural resource use through efficiency increase towards a transition from open to closed cycles of materials and energy" (Ghisellini et al. 2016: 13).[6]

Since circular flows (loops) cannot be completely closed, a (fully) circular economy is, strictly speaking, unrealizable, i.e., it cannot exist. By contrast it is scientifically (physically) correct and (technically, economically …) feasible to adopt the idea of partially closed, i.e. *open* energy and matter circles. The fact that loops can be more or less open, and the fact that there can be few or many of them, explains the need of reconceptualising the notion of *circular economy* in terms of *economy's circularity*, and defining it as a feature of the economy, as the next Section illustrates.

3 The reconceptualization of *circular economy* in terms of *economy's circularity*

3.1 The notion of economy's circularity and the ambiguity of its environmental effects

The theoretical background for our notion of *economy's circularity* is the materials-energy balance model (Ayres and Kneese 1969; Kneese et al. 1970), which depicts the economy-environment relationship in thermodynamic terms. In this perspective, the economy (as an open system) is connected to the environment, which is assumed to be a closed system, through matter and energy flows. By the first law of thermodynamics, every unit of matter entering the economy (in the form of a natural resource) ultimately goes back to the environment in form of material waste (pollution) and lost energy. The materials-energy balance model makes evident that energy and matter flows go from the environment to the economy and back according to a circular path.[7]

The materials-energy balance model provides the appropriate background for illustrating the essence of circularity. In this framework in fact, circularity allows *conserving*, i.e. keeping energy and matter in the economy for longer time (with respect to the case of null circularity). For matter, this means delaying its return to the environment in the form of waste. For energy, this translates into a reduction of the quantity of energy that goes wasted either because embodied in material waste

[6] The idea that loops can be closed is also regrettably present in authoritative policy documents (e.g. EC 2015; EIB 2017; OECD 2009).

[7] With regard to the materials-energy balance model, Pearce and Turner (1989) use two expressions ("circular economy" and "circular economic system") to stress the circularity in the relationship between the economy and the environment. These terms stress the contrast with the case, in which scholars "ignore the environment" (Pearce and Turner 1989: 23), or they include it as a mere provider of natural resources. Pearce and Turner (1989) call this type of representation the "linear system".

or because dissipated.[8] In order to keep energy and matter in the economy, it is necessary to develop a particular type of flows, which re-direct them from their preordinated non-circular path back into the economy. Since these flows have by construction the origin and the end in the economy, they are circular. Moreover, since they are located inside the economy, it is quite natural to call them *internal circles* or *internal loops*. This prompts the following definition of economy's circularity

Economy's circularity is a positive feature of the economy that consists in the presence of internal circular energy and matter flows

According to this definition, circularity is a feature of *any* economy. In other words, every economy has a non-negative degree of circularity, which can be zero (when circular flows are absent) or positive, but in any case, less than one (because loops cannot be closed). This notion of circularity as a feature of the economy is empirically relevant and theoretically consistent at the same time. From an empirical point of view, it captures well the real-world situation, in which every economy has its own degree of circularity that presumably changes over time, either for endogenous reasons or due to policy action. Theoretically, it is correct because it acknowledges that no economy can be circular as a whole, i.e. no economy can be a thermodynamically isolated system. In this perspective, it challenges the idea (see for example, Sauvé et al. 2016; Elia et al. 2017) that a circular economy positions itself in "opposition" (Sauvé et al. 2016, p. 49) to the existing one. Independently from the notion of CE one may have in mind, its core feature is in any case the circularity of flows, and flows cannot be closed. Hence, it stresses the need to think in terms of increasing the degree of circularity in the economy rather than to promote a *transition* from the current economic system to a different one, something that cannot be actually realized. For this reason, claiming that the "circular economy model [...] aims to replace the traditional [...] economy model" (Sauvé et al. 2016, p. 53), appears quite misleading. Coherently with the definition above, higher circularity is viable in the context of, not in opposition to, the current economic system.

Our notion of economy's circularity has three interpretations, which differ for the perspective involved (thermodynamic, economic and environmental and resource-related), but are mutually related. The thermodynamic view allows mapping the full set of (energy and matter) flows, which circularity involves. In a hypothetical scenario with null circularity, there is only one flow (of energy and matter) that unidirectionally crosses the economy. The economic interpretation of circularity complements the thermodynamic one because it allows quantifying the size of the flows identified by thermodynamics. Within physical limits, it is in fact economic forces which finally determine quantities. Finally, the environmental and resource-related interpretation provides information regarding the impacts of circularity on the environment and on the resource use.

From a thermodynamic point of view, the function of the internal circles is to keep energy and matter in the economy. Internal circles absorb energy and matter

[8] The two broad categories of strategies for energy circularity correspondingly involve energy recovery from waste and energy recovery from energy waste streams, as in the case of kinetic energy recovery systems (e.g. Diaz-Elsayed et al. 2009) or waste heat recovery systems (e.g. Kurle et al. 2016).

from the economy, and they give them back (after processing for renewed economic use). Hence, every internal circle is generally coupled with two additional flows. One is the outflow departing from the internal circle and going to the environment. This outflow reflects the fact that no internal circle is closed, and a fraction of the absorbed quantity (of matter or energy) will be inevitably released into the environment (i.e. it goes lost). The other flow is due to the need of providing internal circles with energy and matter. Internal loops are in fact economic activities (e.g. industrial processes) that rely on resources for their operations. In addition to the internal circle and its two associated flows, the last relevant flow to consider is the pre-existent (non-circular) one, which does indeed remain active, albeit at a lower scale. It is plausible in fact, that circular production partly (but never entirely!) replaces its non-circular counterpart. Indeed, were it not so, circularity would simply mean a net expansion of flows (with subsequent environmental and resource-related burdens). Yet, the size of the non-circular flow (as well as of all other flows) depends from economic forces, as the economic interpretation below makes clear.

From an economic point of view, circularity acts as an alternative production technology because it is capable of "providing" things for further use .[9] Already used products and materials (as well as energy and matter residuals) become usable again, either in production or in consumption. Hence, circular production adds production capacity to the pre-existent (non-circular) one. In this perspective, the implementation of circularity may imply higher total (i.e. non-circular plus circular) supply of a given material or product (excluding the case of a fully inelastic demand). Very plausibly, the (new) circular production brings about a crowding-out effect on the (incumbent) non-circular production. *Ceteris paribus*, non-circular production should shrink and circular production should rise. The magnitudes of these changes depend from the degree of substitutability between circular and non-circular production and more in general, from the way the economy reacts to higher circularity. Indeed, the economic interpretation of circularity provides the necessary information for the quantification of its effects.

The thermodynamic perspective on circularity provides the adequate framework for its environmental interpretation.[10] Environmental impacts are in fact directly attached to the thermodynamic flows described above. With regard to the internal circles, impacts are due to the quantities they release (because they are not closed) and to the (energy and matter) residuals connected with their operations. These impacts add to the ones arising from the pre-existent (non-circular) flow. In view of the environmental assessment of circularity, the (additional) impacts due to the internal circles are contrasted with the lower impacts due to the decrease in the non-circular flow. Now, since these two effects are opposite in sign, it is evident that the final effect depends on the specific situation. This prompts the claim that it is theoretically impossible to draw general conclusions regarding the environmental effects of circularity because these effects are *intrinsically* ambiguous. The

[9] We use the expression "providing" in the sense of "making available" to underline that circularity does not always require a production process in narrow sense, as for example in the case of energy cascading.
[10] In view of the aim of the paper, we neglect here the resource-related interpretation.

only environmental motivation for *conserving* (circularity) is clearly a reduction in flows (and hence in polluting emissions). However, this effect is not granted a priori, and for this reason circularity should not be confused with *reducing*, as Sect. 3.2 illustrates.

The thermodynamic interpretation of circularity is the closest to our definition and it is also the most compelling one, as it allows looking at circularity in the most comprehensive way. In this perspective, in fact circularity could be included in those modelling settings where the economy is connected to the environment through matter and energy flows according to thermodynamic principles. These models, which feature inter-sectorial technological relationships based on input–output (IO) systems (e.g. Perrings 1987; Faber and Proops 1993 and more recently Tukker et al. 2009, 2013) would be highly suited to study circularity because of the role given to technology as a key link between thermodynamics, material/energy balances and the economy, and then as a main shaper of circularity. Equally suitable would be the models of the ecological economics tradition, in virtue of their explicit modelling of the economy-environment relationships based on material/energy flows. However, the level of sectoral aggregation of these models is still relatively too high to allow a detailed account of the degree and development of circular flows in the economy. This is particularly true when circular flows involve sectors only partially, as in the case of the paper industry, in which waste paper is also an input in production. This is the main reason why the modelling of circularity also remains very rudimental in more standard settings, as for example, in computable general equilibrium (CGE) models aiming at studying the economic effects of its implementation (for a recent survey, see OECD 2017). Hence, the predominant approach for the investigation of the effects of circularity involves case-specific analysis, as transpires from Sect. 4.

Our notion of circularity has three main strengths. First, it is theoretically grafted in the materials-energy balance model, and hence, it does not need "to be rooted in very diverse theoretical backgrounds" (Ghisellini et al. 2016: 24) nor is it necessary to trace down its precise "origin" within the academic debate.[11] Second, our notion of circularity is simple, while the notion of CE is complex (e.g. Kirchherr et al. 2017; Sauvè et al. 2016) or "holistic" (Jiao and Boons 2014: 21), with the risk to become "elusive" (e.g. de Jesus et al. 2018). Moreover, it is parsimonious.[12] It does not need conceptual superstructures as for example, the notion of umbrella concept

[11] We incidentally observe that the topic of the "origins" of the CE concept is per se an issue in the CE debate. There are in fact authors (e.g. Geissdoerfer et al. 2017; Kirchherr et al. 2017; Merli et al. 2018; Reicke et al. 2018) who hold that the notion of CE has a long "history" (Winans et al. 2017: 825), and authors (e.g. Sauvé et al. 2016) who believe in the "novelty" of this concept. Many authors (e.g. Andersen 2007; Heshmati 2015; Ghisellini et al. 2016; Su et al. 2013; Guo et al. 1997; Geissdoerfer et al. 2017; Lewandowski 2016) for example, attribute the concept of circular economy to Pearce and Turner (1989), who use this wording with a completely different meaning (see note 7) or even to Boulding (1966), who does not even use the word "circular" in his paper. Some authors (e.g. Geissdoerfer et al. 2017) include the blue economy among "the most relevant theoretical influences" (Geissdoerfer et al. 2017: 759) for the CE while others (e.g. Winans et al. 2017) believe that Rachel Carson's book "Silent Spring" has inspired the CE concept.

[12] As far as this can be an asset (see Kirchherr et al. 2017 on this point), our definition of circularity is much shorter than its CE counterparts.

proposed by Hirsch and Levin (1999),[13] and it avoids terms (e.g. "restorative" or "regenerative"), which do not belong to the theory of environmental economics, and risk to create misunderstandings. These terms are contained in various definitions of CE (see for example the one by the Ellen MacArthur Foundation contained in EMF 2012 and in Charonis 2012; Ghisellini et al. 2016; Geissdoerfer et al. 2017). The third strength of our circularity notion is the distinction between *circularity* and *circularity strategies*. As illustrated in the Introduction, the lack of this distinction in the notion of CE is a known source of confusion in the debate (see Kirchherr et al. 2017). A further advantage of separating circularity from circularity strategies is the exclusion of any geographical dimension from the concept of circularity. This does not prevent however geographical differentiation in its implementation, which can vary across "diverse cultural and social and political systems" (Winans et al. 2017: 826).

3.2 Conceptual systematization of the CE debate i.e. Economy's circularity from theory to practice

The reconceptualization of the notion of circular economy in terms of circularity and the formulation of a definition for this concept (see Sect. 3.1) are crucial steps for improving the conceptual clarity of the debate on the CE. Another important step forward in this direction is the development of a *theoretical framework*, which serves providing a (first) conceptual systematization of the overall debate.[14] This framework is composed by four concepts and by the relationships among them. The four concepts are *circularity*, *circularity strategies*, *supporting initiatives* (*actions*), and *circularity projects* (see Fig. 1 below). The notions of circularity and circularity strategies have been already defined (see the Sects. 1, 3.1). *Supporting initiatives* (*actions*) are specific actions that foster the effectiveness and the efficiency *circularity strategies*. Their presence is useful for circularity, but their absence does not preclude its realization. Very intuitive examples of supporting initiatives are design for disassembly, design for recycling and design for modularity (Kalmykova et al. 2018).[15] *Circularity projects* are on-field undertakings to realize strategies in practice.

In the proposed theoretical framework, there are two types of relationships. One is vertical, and it involves the concepts of *circularity*, *circularity strategies* and *circularity projects*. This first relationship is given by the three-level structure of the framework, as visualised in Fig. 1. Going from the top, the theoretical notion of *circularity* stays on the top (level *A*). Level *B* accommodates *circularity strategies*, and *circularity projects* belong in level *C*. Observe that the three levels altogether

[13] For an application of the notion of *umbrella concept* to the CE see for example, Blomsma and Brennan (2017) and Sacchi Homrich et al. (2018).

[14] We are not aware of other similar systematization exercises.

[15] Other examples of supporting strategies are among others, waste management, the "reclassification of the materials into ""technical" and "nutrients"" Ghisellini et al. (2016, p. 16) and the information campaigns aiming at increasing consumers' responsibility for material use and waste.

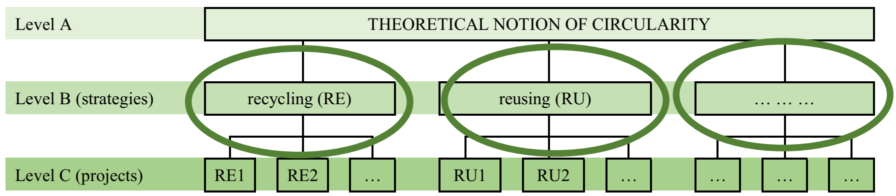

Fig. 1 The theoretical framework (authors' own figure)

resemble a theory-to-practice sequence. The second relationship is horizontal, and it occurs between *circularity strategies* and *supporting initiatives*, which are both located at level *B*. In consideration of their ancillary role, supporting initiatives are schematically collected within a circle around each circularity strategy.[16] The conceptual difference between strategies and supporting initiatives, which our framework allows highlighting, appears to be ignored in the debate. However, this difference is a very important from both from a theoretical point of view and for the implementation of circularity in practice. Just one example will be enough to make the point. In the case of *design for recycling*, firms are fostered in moving towards this type of approach in design. However, it makes little sense to focus on this initiative, if recycling is not contextually implemented.

Albeit rigorous, the structure of the proposed framework is comprehensive by construction. This means that it is ideally capable of accommodating all the concepts arising in the CE debate. It acknowledges in fact, that both *circularity strategies* and *supporting initiatives* evolve over time, with new ones continuously arising. The proposed framework contributes to the conceptual clarity of the ongoing debate in two ways. First, it provides a helpful guide for identifying those concepts, which arise in the debate, but they do not belong to it, and risk to create confusion (see for example concept of blue economy in footnote 12). Second, it may be used to classify properly *circularity strategies* and *supporting initiatives*. While the evolution of existing concepts and the emergency of new ones are very welcome signs of progress in the debate, they often threaten its conceptual clarity. With respect to strategies for example, confusion is still profound, as observed by Reike et al. (2018), who underline a general lack of clear definitions in this area.

Since there are (at least) two papers (Reike et al. 2018; Kalmykova et al. 2018) compiling extensive and meticulous lists of strategies (and supporting actions),[17] fixing (at least most of) the existing conceptual confusion is essentially possible by applying our theoretical framework to the various concepts introduced in the debate. We actually undertook this exercise for Sect. 4, but we will not provide a full report about its outcome here because it would deviate too much from the scope of the paper. We only focus on two concepts, i.e. *reducing* and *energy recovery from waste*

[16] Although our visualization does not make it explicit, *supporting initiatives* clearly vary from strategy to strategy.

[17] According to Reike et al. (2018), there are (at least) 38 different types of strategies (and supporting actions) beginning with "re".

with the following motivations. Reducing plays a central role in the ongoing debate on the CE, with many other concepts resembling (at least partly) this scheme (e.g. refusing, products eco-labelling …). However, a closer look at its nature reveals, in our understanding, that it is incorrect to count it among circularity *and* CE strategies. Hence, our point on reducing is relevant for completing our definition of circularity and fostering the conceptual clarity of the debate. As for energy recovery from waste, our motivation is to argue explicitly that it is a circularity strategy, albeit with noteworthy environmental consequences.

With regard to *reducing*, recall that this is a direct intervention either on the resource quantities, which flow in into the economy, or on the waste quantities, which flow out into the environment. For this reason, it is the core of any environmental policy. The essence of a circularity (or a CE) strategy on the other side, lies in the creation (or in the expansion) of circular flows within the economy. Hence, reducing *per definition* does not directly contribute to higher circularity.[18] Any economy can implement it while leaving its degree of circularity unchanged. It may well be that reducing indirectly induces higher circularity, but this is not a necessary outcome. In this perspective, including reducing among circularity strategies means overlooking that circularity (as a means of *conserving* energy and matter within the economy) may eventually fail to lead to reduction while *reducing* is intrinsically (and tautologically) a way towards reduction. In *reducing*, both aims and means are reduction. In *conserving*, reduction is only the aim, while the means is the creation of circular flows in the economy. While the primary environmental effect of *reducing* is theoretically positive, the primary effect of *conserving* is theoretically ambiguous. This has an important consequence in terms of environmental policy. Implementing a reducing policy surely leads to an environmental benefit. Implementing a circularity policy does not necessarily benefit the environment, as we argued in Sect. 3.1. Since we recognize the paramount role of reducing as a strategy for limiting economy's environmental impacts, we find conceptually wrong and policy-wise dangerous to count it among circularity (or CE) strategies.

Our argument regarding reducing extends to all those strategies, which feature a reducing scheme. These are for example refusing and products eco-labelling. Reike et al. (2018, p. 10) define *refuse* with regard to consumers' and producers' behaviour. As to the former, refuse is "the choice to buy less, or use less" in the framework of "a post-material lifestyle [which includes] rejection of packaging waste and shopping bags". As to the latter, "refuse refers rather to the Concept and Design Life Cycle where product designers can refuse the use of specific hazardous materials, design production processes to avoid waste (Bilitewski 2012) or more broadly speaking, any virgin material." Eco-labelling of consumption articles is for some authors (e.g. Ghisellini et al. 2016) one of the most promising CE strategies, particularly in the EU (EC 2013). Eco-labels are awarded on the basis of strict environmental requirements, which certify that over their entire life cycle, eco-labelled products have a lower environmental impact than their unlabelled counterparts. Hence,

[18] Yet, most authors (e.g. Ghisellini et al. 2016; Kirchherr et al. 2017; Su et al. 2013; Heshmati 2015) include reducing in the their CE discourse.

substituting eco-labelled products for unlabelled products is expected to bring about improvements for the environment. However, since the criteria for eco-labelling relate to a broad set of environmental features of the products' lifecycles, which do not necessarily pertain to circularity, attributing eco-labelling to the domain of CE policies is theoretically inappropriate.

Energy recovery from waste is usually understood as a process of energy production from material waste, which includes (but it is not limited to) waste incineration. According to this definition, it seems correct to include it among circularity strategies, as it allows keeping in the economy (a part of) the energy embodied in the material waste flow. In the alternative non-circular option (i.e. traditional landfilling), this energy would in fact return to the environment. Hence, we agree with Kirchherr et al. (2017), who include energy recovery among CE strategies. As these authors correctly remind, the European Union (EU) itself considers "recover" in its Waste Framework Directive (EC 2008). It is important to remind however, that energy recovery ranks at the bottom of the so-called waste hierarchy, just one rung higher than "disposal" (see EC 2008, art. 4). Indeed, while it is correct to include energy recovery among the circularity strategies, it is hard to disagree that "municipal solid waste (MSW) incineration is one of the significant sources of PCDD/Fs [dioxins] in the environment", which "are among the most toxic chemicals on the earth" (Zhou et al. 2015: 106). This is clearly a very striking case, which we purposely picked because circularity scores very low in terms of environmental performance. Indeed, it provides further motivation for the next section, in which we argue about the ambiguity of circularity in environmental terms.

4 The environmental effects of circularity

Besides the conceptualization of the notion of economy's circularity, the main result of Sect. 3 is that the implications of circularity on the environment are theoretically ambiguous. The purpose of this Section is to provide empirical evidence for this ambiguity. The methodological approach it is based on derives from the intuition of separating *circularity* from the *strategies* for its implementation. According to this approach, the environmental effects of circularity coincide with those of the strategies. Since some circularity strategies (e.g. recycling, energy recovery from waste, reusing …) largely precede the debate on the CE,[19] this CE-related literature is also relevant for our research. We explore diverse strands of literature, whereby each of them deals with a different circularity strategy.

For our discussion to be comprehensive and straightforward at the same time, we divide the selected papers in two groups. The first contains studies that focus on a specific circularity project, they quantify its environmental effects and they compare it with one or more non-circular counterparts. This is indeed the desirable type of exercise because it delivers a first necessary result about the environmental

[19] Research in Municipal Solid Waste (MSW) incineration, for example, dates back the 70's (Zhou et al. 2015).

desirability of circularity. These studies make evident that the impacts of circularity can be only assessed upon detailed case specification. Indeed, were there a general rule behind these cases, the scientific relevance of the related studies would be quite dubious. The second group of studies fails either to provide any quantitative assessment, or to make a comparison with the related non-circular counterpart. This type of literature is in any case relevant for our exercise, as it shows that knowledge about the effects of circularity is at best, incomplete. After Sect. 4.1, which contains a general appraisal of the relevant literature, Sect. 4.2 deals with the first group of studies and Sect. 4.3 reports about the second group.

4.1 General appraisal

In the scientific literature on the CE (e.g. Winans et al. 2017; Ghisellini et al. 2016), an overall environmental improvement following from the CE is often given for granted, or even assumed as a "rule of thumb" (Potting et al. 2017: 4). However, when browsing through the empirical strand of this literature and through the contributions regarding the various specific strategies, it is quite difficult to come across instances of clear, quantitatively proven, environmental improvements following the implementation of the CE. Sometimes, as for example in the case of the environmental effects of CE actions at the aggregate-economy level, the beneficial evidence is due to a conceptual confusion between broader environmental initiatives, which feature higher resource efficiency or decupling of economic growth from resource use, and CE. Nevertheless, contributions reporting positive effects in terms of reductions in specific air polluting emissions in China (Yu et al. 2013), in Japan or in the US (Wang et al. 2013) are included in many surveys regarding CE (Ghisellini et al. (2016), Heshmati 2015). Yet, there is no evidence of the causality between these positive effects and (higher) circularity, as they are at least as likely to stem from broad environmental policies or sustainable development strategies in which CE actions may hardly be at play. In some cases, environmental improvements, which in theory should be a main rationale for implementing circularity, are in practice, at best, a welcome side effect (Ghisellini et al. 2016; Potting et al. 2017). A very interesting example is the case of eco-industrial parks (EIP) projects. In this regard, Ghisellini et al. (2016) note that there seems to be a consensus within several recent studies that the environmental benefits of these projects eventually materialize as a side-effect of purely economic decisions by private firms.

The same literature that reports about the benefits of the CE, explicitly puts forward a series of basic caveats about the possible environmental backfiring of some CE strategies (e.g. Ghisellini et al. 2016; Potting et al. 2017). These caveats are quite serious, and they also affect that type of strategies, which rank high in the waste hierarchy such as reusing. One is that technologies used for recycling and refitting might use more energy than their corresponding non-circular counterparts might. In a prevalently fossil-fuel based economy, there would be risk of generating more polluting emissions than under the "dispose-and-produce-new" scenario[20] (Allwood, 2014). A second issue regards the rebound effects, namely, the possibility that knowing that the fate of goods is to be further used because of circularity, will induce consumers to use them carelessly, as under the influence of a sort of moral licensing effect. Third, there is the possibility that sharing economy practices will give access to polluting goods to a larger share of population. Consumers previously unable to afford the purchase of certain goods, can start using them, as in the case of car use by young people thanks to car sharing services (Potting et al. 2017).

The evidence presented below in this Section suggests that the environmental effects of circularity are necessarily case-specific because technologies, materials and lifecycles are case-specific. Hence, a yet ample selection of cases is actually unable to provide general evidence even with regard to a single strategy. Moreover, some of the studies considered (see Sect. 4.2) show that their scope is often limited to the quantification of some impacts, but they neglect others, which remain unknown. The overall impression is that of a fragmented picture, with a wide variety of approaches and results dictated by the wide variety of technologies assessed. There are indeed some exemplary situations in which a circular approach is beneficial. However no generalization, be it in terms of sector, geography or class of circularity strategies, emerges as manifestly evident from this literature.

4.2 Studies comparing circular and non-circular options

In this section, we review the findings of a selection of studies, which respectively deal with three different classes of circularity strategies, namely energy recovery through incineration, recycling and reusing. The literature on energy recovery from waste through incineration is huge[21] and only one of its subsets contains comparisons with non-circular options. In this case, the non-circular option is pure landfilling without any sort of energy or matter recovery (as in re-mining, for example). This literature originally belongs to the field of LCA studies or to the area of toxicological/eco-toxicological assessment studies. It becomes relevant for our research, once we regard incineration as a strategy for circularity. In this perspective, Damgaard et al. (2010) for example, investigate the environmental impact of incineration, and they compare it to various fossil-based power generation technologies. They find that its environmental performance dominates coal-based energy production in both the standard and toxic impact categories. In the comparison with the non-circular option that uses natural gas however, only the most efficient recovery options entail environmental gains, which are in any case limited to what Damgaard et al. label "standard impacts" (i.e. "global warming, acidification, photochemical ozone formation and nutrient enrichment").[22] At a first sight, this study seems to circumscribe evidence of the environmental desirability of circularity.

[20] Very optimistically, Preston (2012) deems that "The remaining energy needed for a CE would be provided by renewable sources." (Preston 2012: 3).

[21] In their survey, Wang et al. (2016) list 4348 studies since 2000.

[22] Damgaard et al. (2010), p. 1247.

However, the overall assessment neglects the landfill-related externalities, which cannot be neglected in case no incineration occurs. Cucchiella et al. (2017) show that for a specific configuration of incineration plant, waste-to-energy is not only beneficial for the environment, but it is also economically profitable, compared to landfilling. Allowing for co-generation would increase the environmental benefits but would significantly reduce profitability. Similarly, Bhering Trindade et al. (2018) using an LCA approach, find positive environmental effects in comparing a Brazilian incineration plant (located in the city of Santo André in São Paulo State) under more environmental-friendly configurations than the standard operational settings, in terms of significant reductions in CO_2 emissions and in terms of energy recovered in the process. Analogous results are found for Iran by Nabavi-Pelesaraei et al. (2017). Cherubini et al. (2009) compare four methods of urban waste treatment for the municipality of Rome. They look at a wide range of polluting emissions by coupling standard LCA with other methodologies such as for example, material flow accounting (MFA) and environmental footprint. Rather unsurprisingly, they find that traditional landfilling is the worst option, while a sorting plant coupled with electricity and biogas production appears to be the least harmful one for the environment among the options considered.

With regard to recycling, there is a substantial number of environmentally beneficial cases. For instance, Jin et al. (2016) find that in the case of neodymium-iron-boron magnets, recycling brings about significant environmental benefits compared to the production of new magnets from virgin ores. In the case of tires, Landi et al. (2016) study the environmental effects of recycling textiles fibres from exhaust tires and of using them in the production of asphalt and plastic compounds. They find recycling to be environmentally preferable to landfilling and incineration, even though the recovered fabrics need to undergo a cleaning process. Although the environmental impact of this cleaning process does not clearly transpire from the paper, the recycling option appears to dominate both landfilling and incineration from the point of view of the impacts on ecosystems and on human health. Recycling can also lead to undesirable consequences, however. This is for instance the case of plastics, because of the release of additives during the recycling process (see e.g. Hahladakis et al. 2018). In any case, the environmental impacts significantly vary according to the specific recycling procedure adopted. With regard to aluminium recycling for example, Grimaud et al. (2016) show that recycling generally brings about substantial environmental benefits in comparison with primary production. At the same time, however, these authors point out that some recycling options (e.g. heat processing) are less beneficial than others (e.g. cold processing). Similarly, Boyden et al. (2016), who study the case of alternative options for end-of-life treatment of lithium-ion batteries, find that environmental impacts vary according to the process used, and within each process, to the various components of the process. In the case of hydrometallurgical processes, landfill is the main impact source in terms of global warming and terrestrial eco-toxicity potential, while electricity generation is the most relevant source of concern in terms for human toxicity potential. In the case of pyro-metallurgical processes, the largest impacts originate from electricity generation for human toxicity potential and terrestrial eco-toxicity potential and from plastics incineration for global warming potential. Landfill is found to be the most toxic alternative, while the hydrometallurgical process generates larger global warming impacts than both pyro-metallurgy and landfill.

A very interesting paper in the area of reusing is the one by Genovese et al. (2017), who develop a novel methodological framework to assess the environmental effects of this strategy. They combine a bottom-up LCA approach with a macro-economic top-down, multi-regional input–output framework, and they apply their approach to two case studies. One is in the chemical sector, and it features the reuse of ferrous sulphate (a by-product in the titanium supply chain), in water treatment processes in place of ferric chloride. The other is in the food-processing sector, and it consists in reusing cooking oil for biodiesel production. In both cases, the reuse of by-products, which were otherwise discarded, bring about tangible environmental benefits in terms of reduced carbon emissions along the two supply chains considered. In the chemical sector case, the overall emissions from the ferrous sulphate chain drastically shrink to about one-third of those from the ferric chloride chain. In the food processing case, the circularity alternative brings about a more modest but still significant reduction in carbon emissions (− 40%). The contribution by Genovese et al. (2017) provides a clear case for circularity. As the authors observe in their concluding remarks however, a richer set of indicators could be considered, and the methodology could be refined. This on one hand confirms the difficulty to capture the totality of effects, and on the other, the importance of methodology.

4.3 Studies without a comparison with a non-circular counterpart

The studies considered in this section refer to three strategies, namely energy recovery from waste, refurbishment and industrial symbiosis. The literature on energy recovery through waste incineration is huge, as noted in Sect. 4.2, and many papers do not contain a comparison with a non-circular counterpart. This is for instance, the case of Beylot and Villeneuve (2013), who analyse the environmental performances of 104 incineration plants in France. They consider a number of impacts (related to climate change, photochemical oxidant formation, particulate matter formation, terrestrial acidification and marine eutrophication) and they find huge variability across plants. Depending on where it is treated, burning one ton of waste could result in a reduction of 58 kg of CO_2-eq to increases up to 408 kg of CO_2-eq (with respect the average value of the plants considered). Studies such as the one by Beylot and Villeneuve (2013) are relevant for our analysis because they provide evidence of the importance of being as specific as possible when performing LCA impact assessments, while arguing for the irrelevance of approaches, which rely on standard "average plant" values.

In the case of refurbishment, the comparison with the non-circular alternative is hardly ever the focus of the studies we encountered, and when present it is often a passing remark not underpinned by any rigorous quantitative comparison (e.g. Kamigaki et al. 2017) or a mention of related results in the literature (e.g. Mugge et al. 2017). Kamigaki et al. (2017) for example, deal with photocopier refurbishing in Japan, and they mention a substantial reduction in CO_2 emissions (− 80%) in comparison to the "dispose-and-produce-new" scenario. However, it remains unclear how this result is computed. In other cases (e.g. mobile phones) there is little evidence of such benefits, and interestingly, even very little awareness in the public (van Weelden et al. 2016). Nevertheless, there is also a number of papers, which give the environmental benefits of choosing a refurbished phone over a brand new one for granted (e.g. Mugge et al. 2017).

The principles of industrial symbiosis foresee clusters of firms that concentrate selected production and logistics activities in a given area, also called eco-industrial parks (EIP). The idea is to maximize synergies and to exploit the residual productive values of by-products of some chains that can feed in as useful production input into other chains. This should ultimately increase the overall resource efficiency of the cluster, with a possible environmental benefit. Ghisellini et al. (2016) list numerous examples of such initiatives. Among the many examples worldwide, however, the only one with clear positive environmental effects is the EIP in Kalundborg (Denmark). Quite curiously, the environmental improvements were not part of the project at the beginning. Indeed, it took one decade for the participant firms to become aware of these positive implications and another decade to gain international acknowledgment at the Sustainable Development Conference in Rio in 1992. The contrast between environmental potentialities and actual performance is particularly striking in Chinese industrial symbiosis initiatives. For such initiatives, environmental protection is an explicit objective of the Chinese State Environmental Protection Administration in promoting EIPs. However, a clear-cut appraisal of the environmental improvements is hard to find in the case studies reviewed by Ghisellini et al. (2016). Even when explicitly mentioned, as in the case of the Shenyang Economic and Technological Development Zone (SETDZ), for which "relevant environmental and economic benefits" were found by a governmental assessment, they are not disentangled from economic efficiency ones, nor are they clearly quantified. For the SETDZ, Ghisellini et al. (2016) do mention a study by Dong et al. (2013), who provide a measure of the carbon footprint of the project that includes both upstream and downstream impacts. However, from the study does not transpire whether the establishment of the Zone resulted in an environmental improvement or not.

5 Conclusions

This paper aims at contributing to the current debate on the CE in two directions. The first is to provide more theoretical clarity and eventually increase the scientific relevance to the debate. The second is to investigate more closely the relationship between CE and environment. We start with a critical re-visitation of the notion of CE, and we provide the theoretical background for introducing the notion of *economy's circularity*. Next, we show that the environmental effects of (an incremental change in) circularity are theoretically ambiguous. For policy-making, this finding is very important because it challenges the idea of circularity as a promising tool in environmental policy. To make this point, we illustrate a limited but meaningful number of issues, which can undermine *environmental* circularity policies in one (or more) of their aspects (effectiveness, efficiency and feasibility).

Our approach at enhancing the theoretical clarity of the debate on the CE is based on the notion of *economy's circularity*. Although many contributions in peer-review journals continue to foster the "closing-the-loop" idea, we recall that loops cannot be closed, as it is well-known since at least Daly's work in 1977. Since closed loops are unfeasible, the concept of CE is automatically inconsistent from a thermodynamic point of view and it should be dismissed. With this motivation, we propose the notion of *economy's circularity*, which we define as a feature of the economy that consists in the presence of circular energy and matter flows within it. In virtue of this definition, our notion of *economy's circularity* is compatible with thermodynamics, and it can be easily rooted in the materials-energy balance model (Ayres and Kneese 1969; Kneese et al. 1970). Moreover, it postulates the conceptual distinction between *circularity* (as a feature of the economy), and *circularity strategies* (which allow its implementation, together with supporting initiatives). Elementary as it is, we find that this separation is crucial both for the theoretical clarity of the debate and for the methodology to adopt when studying the effects of circularity.

The separation between circularity and circularity strategies allows two major steps forward in terms of theoretical clarity of the debate. First, it clarifies that a positive feature of the economy (i.e. circularity) cannot be confused with the ways to modify it (i.e. circularity strategies and supporting initiatives). Intuitive as it can be, so far this point has not taken centre stage in the debate, although its relevance for research progress on circularity (CE) seems quite unequivocal. The separation between circularity and circularity strategies provides in fact a practical solution to the problem—highlighted by Kirchherr et al. (2017)—that the essence of circularity will remain unknown until there will be no agreement around the strategies to realize it. Indeed, this distinction acknowledges the importance of granting both theoretical stability to the notion of circularity *and* practical flexibility to circularity strategies (and supporting initiatives), which are by nature in continuous evolution. The second step forward is the construction of a theoretical framework that can enable a conceptual systematization of the whole debate on the CE. To the best of our knowledge, this framework is the first exercise of this kind. The framework, which is based on the notion of circularity, facilitates the identification of non-pertinent concepts, which often pop up in the debate, and it guides the classification of the relevant concepts distinguishing between *circularity strategies* and *supporting initiatives*.

With regard to the methods for studying the effects of circularity, the separation of circularity from *circularity strategies* opens the way to a novel approach. If the strategies are the instruments to implement circularity, then studying the effects of circularity actually means studying the effects of the strategies used. Again, this is a very intuitive point with very important implications. It allows in fact highlighting that the theoretical effects of circularity are ambiguous because they are necessarily case-specific. They depend in fact from the specific circularity strategy, from the project for its concrete realization and, more in general from the way the economy reacts to it. With particular reference to the environmental effects of circularity, the basic point is that virtually no circularity project has zero environmental impacts. Circularity projects usually require energy and material inputs to operate, which, as a rule, end up back into the environment. Since loops are not fully closed, they also generate residuals in the form of waste or pollution. At the same time, higher circularity should lead to lower non-circular production. Hence, the overall environmental effect results from the comparison between the costs of higher circularity and the benefits of lower non-circularity or equivalently, from the comparison between the costs associated with the *status quo* and the costs of the scenario with higher circularity. We corroborate our point regarding the theoretical ambiguity of the environmental effects of circularity by showing that there is only a limited number of studies in the huge CE (and CE-related) literature that provide a transparent quantification of the environmental effects of a given circularity project in comparison to its non-circular counterpart. As meticulous they can be, these studies are clearly case-specific and in most cases, their findings look at the environmental effects in terms of volumes of emissions, not in terms of damages. Our finding regarding the intrinsic ambiguity of the theoretical effects of circularity on the environment provides a theoretical explanation for the general inconclusiveness of the debate on this point, as highlighted by several literature reviews.

In policy perspective, the ambiguity of the environmental effects of circularity justifies the question about its potential as an environmental policy strategy. A general increase in circularity in fact, may risk proving environmentally ineffective or even harmful unless the adopted circularity projects are duly specified. This means that any *environmental* circularity policy necessarily needs a case-specific evaluation to provide appropriate scientific evidence that its implementation yields higher environmental benefits in comparison to its non-implementation. Yet, this evaluation may turn out to be particularly costly in terms of time and financial resources, with the non-negligible risk that it may eventually fail to provide the necessary evidence to draw a final decision. This suggests that using circularity as an environmental policy strategy can be much more difficult than adopting already well-established reducing policies. Reducing policies in fact, have reduction as their objective, and their effect is *theoretically* unequivocal. Circularity polices have conservation (of energy and matter in the economy) as their objective, but conservation is not necessarily reduction. This is not to say that there is no scope for environmental circularity policies. However, this type of policies may turn out to be fairly costly in order to be effective, efficient and politically acceptable. Hence, a lot of research appears to be still needed before environmental circularity policies can be deployed on such a scale to grant a reversal in the current trend of growing pollution.

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