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Value creation and the circular economy

A tale of three externalities

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Abstract

By using resources more efficiently, resource users help to overcome the inherent resource scarcity on "spaceship earth." One strategy in this context is to close resource loops and to use resources circularly. With fewer resources wasted, a more circular use of resources should also increase the efficiency of resource use and create more value. However, when resource users aim for a greater degree of efficiency, inadvertently they might contribute to resources being used less rather than more circularly and, consequently, less instead of more efficiently. We show how to assess the value that is created by the efficient use of resources for the case of linear and circular resource use. This allows us to identify three distinct types of positive externalities related to the circular use of resources: (1) systemic static externalities; (2) idiosyncratic dynamic externalities; and (3) systemic dynamic externalities. We describe how the value created by these externalities can be assessed and argue that they need to be considered when evaluating environmental resource use.

KEYWORDS
circular economy, eco-efficiency, externality, industrial ecology, resource use indicator, value creation

1 | INTRODUCTION

Like a spaceship, planet Earth has a fixed set of resources for a very long, potentially infinite journey (Boulding, 1966). The efficient use of resources extends the duration of this journey. One solution stems from the circular economy (Geissdoerfer et al., 2017; Ghisellini et al., 2016; Pearce & Turner, 1990) which emphasizes the virtues of closing resource loops. In a perfectly circular economy, that is, where wastage is zero, resources are used indefinitely, which subsequently means that the efficiency of resource use is infinite. Arguably, this would also mean that resources continue to create value indefinitely.

However, whilst intuitively appealing, in reality, resource use is imperfectly circular, and hence constitutes a more complex system in practice. For instance, individual resource users (e.g., firms) play a central role in resource use efficiency, as organizational decision-makers decide the way(s) in which resources are used (Shrivastava, 1995). On the one hand, for firms that are interested in sustainable resource use, there has long been a plethora of indicators and assessment techniques available (Franklin-Johnson et al., 2016; Herva et al., 2011; Keeble et al., 2003; Roca & Searcy, 2012; Saidani et al., 2019), as well as more "macro" level analyses that are additionally useful for policy makers (Eckelman & Daigo, 2008; Mayer et al., 2019; Pauliuk et al., 2021). On the other hand, these often follow different logics, obfuscating a supposedly clear direction in the operational changes needed to enhance eco-efficiency: One indicator might prioritize one set of actions, whilst another might prioritize a different set.

A further dimension to the complexity of imperfect circular systems stems from recent work that challenges that circularity always procures efficient resource use. Rebound effects are an example (Corvellecet al., 2022; Figge & Thorpe, 2019; Siderius & Poldner, 2021; Zink & Geyer, 2017). Even more recently, Figge et al. (2021) highlight that when resources flow between users, as they do in circular systems, aggregating the outputs of individual assessments of eco-efficiency fails to accurately reflect macro-level resource use. Instead, they emphasize that approaches to assessing the eco-efficiency of circular systems must be made at the group level.

However, Figge et al. (2021) do not indicate the extent to which aggregation of individual resource user activity is adequate, and perhaps more importantly, how to address the issue. Nevertheless, they do question whether indicators and assessment techniques that are designed to assess the eco-efficiency of individual resource users (e.g., firms) are fit for purpose in the context of imperfect circular systems, and we follow suit.

In this paper, we show the beneficial effects of circularity on the efficiency of resource use. In particular, we demonstrate how these effects can be expressed in monetary terms and where they occur in the interplay between resource users. We identify three positive externalities of circular resource use and show how they can be assessed. Overall, this enables us to better understand the dynamics of circular resource use from both the perspective of the individual resource user and society overall.

Our starting point is that a more eco-efficient use of resources creates value. We use the notion of opportunity costs to assess the value created by a more efficient use of resources (Figge & Hahn, 2005). The use of a resource creates value when it is used more efficiently than by its alternative use. Using opportunity costs we assess the value that is created in absolute monetary terms. An assessment in absolute monetary terms allows us not only to compare the value that is created by different resource users and uses in isolation but also the value that is created jointly. Our findings apply analogously to any other indicator or assessment technique that is based on an efficiency logic.

The rest of our paper is structured as follows. In the next section we discuss the link between the circular economy and the notion of eco-efficiency. The third section shows how eco-efficiency can be assessed in absolute monetary terms. We show that circular resource use creates positive externalities and we show how these externalities can be assessed in absolute terms. In the fourth section, we unpack and discuss our contribution before concluding with some final comments.

2 | CIRCULAR ECONOMY AND ECO-EFFICIENCY

The ideas that natural resources are scarce and that we need to use less of them are not new (Commoner, 1972; Cumming & von Cramon-Taubadel, 2018; Ehrenfeld, 2005; Myers & Kent, 2003). Using natural resources more efficiently is a promising means of reducing resource use (Reijnders, 1998; Schmidt-Bleek & Weaver, 1998; von Weizsäcker et al., 1998). This has commonly been referred to as eco-efficiency (DeSimone & Popoff, 1998; Ehrenfeld, 2005; World Business Council for Sustainable Development, 2000).

At the same time, the (eco)efficient use of resources does not guarantee that resources will be used sustainably. Rebound effects (Berkhout et al., 2000; Hertwich, 2005; Jevons, 1866), for example, are not uncommon: More efficient resource usage can trigger a higher use that partly, fully, or even overcompensates the efficiency-induced reduction of demand for that resource. This effect is exacerbated first by an expanding global population, and second, increasing affluence in many parts of the world. In other words, more people desire more goods increasing overall resource use. Thus, more efficient resource use is likely to be a necessary, but not sufficient condition for a sustainable resource use (Bjørn & Hauschild, 2013; Chertow, 2000; Ehrlich & Holdren, 1971; Hauschild, 2015; Mont & Plepys, 2008). Put simply, to become sustainable we must use resources more efficiently, whilst being mindful of socio-economic constraints.

"It has been widely recognized that C[ircular] E[conomy] could help improve resource productivity and eco-efficiency, [...], and achieve sustainable development" (Yuan et al., 2006, p. 5). Circular modes of natural resource use contribute toward eco-efficiency in ways that linear systems cannot. In contrast to the latter, which wastes resources after a single use, circular systems aim to close open loops (Pearce & Turner, 1990). In its ideal state resource wastage is zero and resources are used indefinitely, creating a positive return with every use and reuse. When perfect circularity is reached the eco-efficiency of virgin resource use is infinitely high (Figge et al., 2017). Again, as above, however, it is difficult to find examples of perfect circularity in practice (Ghisellini et al., 2016). Research has looked into how many times resources are used in our global economy before they are lost. In a fully linear economy resources would be used once. In a perfectly circular economy resources would be infinitively often. Today, iron, for instance, is used 2.67 (Daigo et al., 2005), copper 1.9 (Eckelman & Daigo, 2008), and nickel 3 times (Eckelman et al., 2012)—allowing for some geographical variations (Klose & Pauliuk, 2021). This shows that perfect circularity is somewhat unrealistic in practice.

At the same time, research continues to explore various means of maximizing the efficiency of resource use. Bocken et al. (2016), for instance, distinguish between the three strategies of slowing, closing, and narrowing resource flows to decrease resource use and thus increase (eco)efficiency. In terms of a "slowing" approach, products and services are used for longer, meaning that fewer resources are used over time as resource flows decrease in their intensity. In respect to a strategy of "closing," the goal of the circular economy is to close resource flows by ensuring that the same unit of resource is repeatedly used, thus increasing (eco)efficiency. But it is the third strategy of "narrowing resource flows" that eco-efficiency research has tended to focus on so far. In this approach, fewer resources are used to achieve the same purpose, dematerializing our economy by a factor of 4 (von Weizsäcker et al., 1998), 10 (Schmidt-Bleek & Weaver, 1998), or more (Reijnders, 1998). Narrowing resource flows in this way is

TABLE 1 Sustainable value: Linear case

Firms	A_1	A_2	A_3	A_4	A_5	B_1	B_2	B_3	B_4	B_5	Total
Return	150	150	150	150	150	200	200	200	200	200	1750
Resource	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	10,000
Efficiency	0.15	0.15	0.15	0.15	0.15	0.2	0.2	0.2	0.2	0.2	0.175
Value spread	−0.025	−0.025	−0.025	−0.025	−0.025	0.025	0.025	0.025	0.025	0.025	
Sustainable value created	−25	−25	−25	−25	−25	25	25	25	25	25	

primarily discussed in the context of linear resource flows. However, all three strategies can be used in combination: fewer resources can be used to produce a given product (narrowing), that can be designed to be used for longer (slowing), and at the end of life the embodied resources could be recuperated (closing).

It is typically assumed that different efficiency strategies are either independent of each other or that "the strategies of slowing and closing (and narrowing) resource flows can be mutually reinforcing" (Bocken et al., 2016, p. 317). Yet this is not always the case. A resource user using resources more circularly might redirect resource flows away from other secondary and tertiary uses that could have increased the efficiency of resource use to an even greater extent, producing a symbiotic rebound effect (Figge & Thorpe, 2019). We argue that similar symbiotic effects can occur when the three strategies of narrowing, slowing, and closing are combined.

In the following section we first show how eco-efficiency can be assessed when resource use is linear. Subsequently we develop the approach to extend to circular resource use, furthering our understanding as to how it creates value.

3 | ASSESSING ECO-EFFICIENCY IN ABSOLUTE MONETARY TERMS

Eco-efficiency is a two-dimensional, relative indicator (Callens & Tyteca, 1999; Huppes & Ishikawa, 2005). To understand the absolute impact on value creation and to compare different aspects of value creation, a one-dimensional absolute indicator is required. To arrive at a one-dimensional, monetary indicator, environmental resources need to be priced in monetary terms. Whilst many different monetary assessment techniques exist (Hofstetter & Müller-Wenk, 2005; Stechemesser & Guenther, 2012), sustainable value uses the concept of opportunity costs (Bastiat, 1870) to price resources: Resources create value when they are used more efficiently than by their alternative use (Figge, 2001; Figge & Hahn, 2004, 2005). Essentially, this is not a new idea (Green, 1894), but it is applied predominantly to economic capital to this day (Jasinski et al., 2015). Today, it is commonly assumed that the cost of economic capital equates to the opportunity cost of capital (Modigliani & Miller, 1958). This way of pricing resources can also be applied to economic, environmental, and social resources. Applied to *natural* resources, this implies that natural resources create value when they are used more eco-efficiently than in alternative uses.

To illustrate the approach, suppose a scenario of ten resource users (firms A_1–A_5 and B_1–B_5). Each firm uses a natural resource to create a return. Firms A_1–A_5 each use 1000 units of the resource to create individual returns of 150. Firms B_1–B_5 also each use 1000 units of the resource but create individual returns of 200. Based on this information, we can calculate the efficiency of resource use in all firms A_1–B_5. Firms A_1–A_5 each have an efficiency of resource use of 0.15, while Firms B_1–B_5 each have an efficiency of 0.20. We know that in total a return of 1750 is created and 10,000 units of resources are used across all firms. This results in an efficiency of resource use of 0.175 overall, that is, when Firms A_1–B_5 are considered collectively.

In a next step, we determine the extent to which resources are used more or less efficiently by each firm, in comparison to the efficiency of resource use overall, that is, when compared to the opportunity cost. For each unit of resource it uses, Firm A_1 creates, for example, 0.025 less return than the average of Firms A_1–B_5 taken together. Knowing that Firm A_1 employs a total of 1000 units of the resource, we also therefore know that A_1 creates 25 (0.025 × 1000) units less return than if the resource had been used by all resource users on average. We refer to this as sustainable value (Figge & Hahn, 2004, 2005). In essence, Firm A_1 destroys value, as it lags behind in terms of the return it generates.

The sustainable value for all other resource users (A_2–A_5 and B_1–B_5) is calculated analogously (Table 1).

So far, we have modeled resource use as linear; resources were used once and then discarded. We now introduce some extent of circularity into the same example of 10 resource users, that is, Firms A_1–B_5. To show the effect clearly, we only apply circularity to the first group of resource users (Firms A_1–A_5) that herein we refer to as Group A. The other resource users—Group B (Firms B_1–B_5)—continue to use resources linearly.

In Group A, Firm A_1 passes 80% of its resources on to Firm A_2 after the resources' initial use. After reuse by A_2, the firm passes on 80% of the resources it received from Firm A_1 to Firm A_3. This continues down the line until what remains of the resources of A_1 gets passed on to A_5. Again, for analytical clarity, we limit ourselves to looking at the resources of A_1 that are passed on within Group A.

TABLE 2 Sustainable value: Imperfect circular resource flows

		Group A					Group B					
	Firms	A_1	A_2	A_3	A_4	A_5	B_1	B_2	B_3	B_4	B_5	Total
	Return	150	150	150	150	150	200	200	200	200	200	1750
	Total resources	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	10000
	A_1 resources		800	640	512	410						
	Virgin resources	1000	200	360	488	590	1000	1000	1000	1000	1000	7638
Basis: Total resources	Efficiency	0.15	0.15	0.15	0.15	0.15	0.2	0.2	0.2	0.2	0.2	0.175
	Value spread	−0.025	−0.025	−0.025	−0.025	−0.025	0.025	0.025	0.025	0.025	0.025	
	Sustainable Value created	−25	−25	−25	−25	−25	25	25	25	25	25	
Basis: Virgin resources	Efficiency	0.15	0.75	0.42	0.31	0.25	0.20	0.20	0.20	0.20	0.20	0.23
	Value spread	−0.08	0.52	0.19	0.08	0.02	−0.03	−0.03	−0.03	−0.03	−0.03	
	Sustainable value created	−79.11	104.18	67.52	38.20	14.74	−29.11	−29.11	−29.11	−29.11	−29.11	
	Sustainable value (group)	145.53					−145.53					

Table 2 demonstrates how resources flow in both groups in the first period. There are no changes for Group B. Resource flows are more complicated in Group A though when circularity is introduced. In Table 2, we can see how Firm A_1 also requires 1000 units of virgin resources. However, rather than discarding all resources at the end of their initial use, A_1 passes 800 units on to Firm A_2. A_2 therefore only requires 200 units of virgin resources to use 1000 units of total resources overall. The same principle applies analogously for Firms A_3 to A_5. In short, the resources passed on by Firm A_1 help to reduce the need for virgin resources across all firms of Group A.

We can now calculate the value that is created first based on total resources used by each firm, and second, based on virgin resources used. The value that is created based on total resources used remains unchanged from Table 1. This is helpful as it tells us how efficiently firms use their resources operationally within the boundaries of their own activities.

Results differ, however, when we base our analysis on the use of virgin resources. The overall efficiency of resource use, that is, generated collectively by Firms A_1 to B_5, increases from 0.175 to 0.23. Importantly, 0.23 lies above the efficiency of resource use by all firms in Group B, meaning that Firms B_1–B_5 are all value destroying organizations: Each firm in Group B now destroys 29.11 units of value. The performance of Firm A_1 is even more detrimental, as it not only requires 1000 units of resources but also only generates a return of 150 units. This results in Firm A_1 having the lowest (eco)efficiency of all 10 firms, and the lowest value creation of −79.11.

As Table 2 indicates, Firm A_2 creates the most value (104.18). This is because the resources that it receives from A_1 replace the use of the virgin resources A_2 would have needed to use in linear systems. Essentially, reusing A_1's resources dramatically increases the eco-efficiency of virgin resource use. Firms A_3–A_5 also individually benefit from this effect, albeit to a lesser degree.

Figge et al. (2021) argue that circular systems of resource use need to be assessed and interpreted at the group level, rather than at the level of the individual resource user, that is, within the activities of each specific firm. And in Table 2 we can see the logic of this suggestion quite clearly when we compare value creation for Group A (A_1–A_5 as a whole) to Group B (B_1–B_5 as a whole): Together, Firms A_1–A_5 create value, whereas Firms B_1–B_5 together destroy value.

The implications of our argument revolve around the purpose of indicators and assessment techniques, in that ideally, they support managerial decision-making as well as that of policy makers (Dahl, 2012; Pintér et al., 2012). A negative sustainable value points to an inefficient use of resources, and thus the logic is that by allocating resources to firms that generate positive value, resources will be used more (eco)efficiently. Yet, as we have shown, this can be misleading. From our example, we showed how Firm A_1 was responsible for destroying the most value—compared to the other nine firms. But if A_1 was eliminated, its resources could not be passed on to A_2—the firm that created the most value (based on virgin resource use). Subsequently, A_2 would not only have to substitute A_1's resources with virgin resources, but it would also be unable to pass on these resources to Firm A_3, which would have to revert to using virgin resources as well. The same logic applies further down the chain, that is, to Firms A_4 and A_5. Put in more general terms, whilst Firm A_1—as an individual entity—uses resources inefficiently, it creates a positive externality that more than compensates the inefficiency of its own resource use.

So far, we have looked at a single period. In other words, when resources reach A_5, they are not passed on any further. We now close this loop by assuming that Firm A_5 passes on 80% of the resources received in the next period back to A_1, which, in another complete cycle, will pass 80% of resources to Firm A_2, and so on down the chain of Group A. Our analysis though is still focused on the resources of period t_0, but now also considers what happens with these resources in subsequent periods (t_1–t_∞), as seen in Table 3.

TABLE 3 Imperfectly circular resource use over several periods: Resource flows

		Group A					Group B				
	Firms	A_1	A_2	A_3	A_4	A_5	B_1	B_2	B_3	B_4	B_5
t_0	Return	150	150	150	150	150	200	200	200	200	200
	Total resources	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
	A_1 resources		800	640	512	410					
	Virgin resources	1000	200	360	488	590	1000	1000	1000	1000	1000
t_1	Reused resources	327.70	262.10	209.70	167.80	134.20					
t_2		107.40	85.90	68.70	55.00	44.00					
t_3		35.20	28.10	22.50	18.00	14.40					
t_4		11.50	9.20	7.40	5.90	4.70					
$t_{\dots}$		…	…	…	…	…					
t_∞		0	0	0	0	0					
Total (all periods)		1487	1390	1312	1250	1200	1000	1000	1000	1000	1000

TABLE 4 Returns created by resources present at t_0: Imperfectly circular resource use

	Group A					Group B				
Firms	A_1	A_2	A_3	A_4	A_5	B_1	B_2	B_3	B_4	B_5
t_0	150	150	150	150	150	200	200	200	200	200
	Due to A_1 resources									
	150	120	96	77	61					
t_1	49.15	39.32	31.46	25.17	20.13					
t_2	16.11	12.88	10.31	8.25	6.60					
t_3	5.28	4.22	3.38	2.70	2.16					
t_4	1.73	1.38	1.11	0.89	0.71					
$t_{\dots}$	…	…	…	…	…					
t_∞	0	0	0	0	0					
Total	223	208	197	187	180	200	200	200	200	200

In Table 3, period t_0 is identical to Table 2 but shows for subsequent periods the amount of resources that are passed on at the end of period t_0 from A_5 back to A_1, and that consecutively flow from A_1 back down the chain of firms in Group A.

As in Table 2, at each step 80% of resources are passed on and 20% are wasted. Whilst the actual amounts of resources that are passed on decline at each step, this process is theoretically never ending and can be modeled with a geometric series. With all other factors being equal, at each step these resources create a return. We can now determine this return. Firms A_1–A_5 all individually use 1000 units of resource and create a return of 150 units at t_0. Some of the return of firms A_2–A_5 is created using the resources that A_1 has passed on. The return of A_2 at t_0 (80%)—120 out of the total return of 150—is, for example, due to the resources it has received from A_1.

Some of these resources return to the resource users at a later stage ($t_1, t_2, \dots$) and create more return. If we assume that resources are used with the same efficiency at every step, we can estimate the return that is created at later periods. For example, Firm A_1 reuses 327.70 units of resource at t_1. Assuming that A_1 continues to use resources with an efficiency of 0.15 we can estimate the return that is created at t_1 with these resources to be 49.15. We can calculate the return that is generated by each firm in every period accordingly. Table 4 summarizes these calculations.

Overof the whole duration that A_1's resources are used and reused, that is, until all its resources are rendered as waste, they will have generated a return of 223 for A_1. A_2 will create—with the virgin resources it uses and the resources passed on from A_1 that it reuses—a return of 208. Firms in Group B (B_1–B_5) use their resources linearly, that is, only once, which means they can only create a return of 200 each at period t_0, with no further activity possible unless new resources are used (not modeled). For the firms in Group A, all returns during period t_1 and onward (grey area in Table 4) are created using the resources initially passed on by Firm A_1 at t_0. This equates to an additional return of 246.

We can use the information on the value created (Table 4) and the virgin resources used by each resource user (Table 2) to calculate the sustainable value that is created (Table 5).

TABLE 5 Sustainable value of circular resource use

	Group A					Group B					
Firms	A_1	A_2	A_3	A_4	A_5	B_1	B_2	B_3	B_4	B_5	Total
Return	223.11	208.49	196.79	187.43	179.95	200	200	200	200	200	1995.77
Virgin resources	1000	200	360	488	590	1000	1000	1000	1000	1000	7638
Efficiency	0.22	1.04	0.55	0.38	0.30	0.20	0.20	0.20	0.20	0.20	0.26
Value spread	−0.04	0.78	0.29	0.12	0.04	−0.06	−0.06	−0.06	−0.06	−0.06	
Sustainable value	−38.17	156.23	102.73	59.92	25.69	−61.28	−61.28	−61.28	−61.28	−61.28	
Sustainable value (group)			306.40					−306.40			

In Table 5, Firm A_2, for example, requires only 200 virgin resources as A_2 receives 800 units from Firm A_1 at t_0. Over time A_2 creates an overall return of 208.49 (see Table 4), resulting in an efficiency of 1.04. The 10 firms collectively use 7638.40 units of resources to create a return of 1995.77, that is, the overall efficiency of resource use is 0.26. A_2 consequently creates 0.78 units of return more than the average with every virgin resource it employs, which equates to a sustainable value creation of 156.23.

Similar to the effect observed above for a single period (Table 2), Firm A_1 does not create sustainable value directly even when several periods are taken into account. At the same time, the sustainable value created by Firms A_2–A_5 would be impossible without the resources that are passed on from A_1. On top of the return that is created by Firms A_2–A_5 with the aid of resources passed on from A_1 during t_0 there is, as before, a return of 245.76 that is created overall by Group A during the periods of t_1 and onward. This constitutes a positive externality—generated by the resources of a single firm, that is, A_1. On the one hand, the magnitude of the externality depends on the amount of resources passed on by the initial resource user (Firm A_1 in our example). On the other hand, how efficiently subsequent firms within the group (e.g., A_2–A_5) reuse the resources that are passed on to them is also important. This demonstrates the symbiotic relationship between resource users that the circular economy creates.

The resources used by Firm A_1 in our example create four different types of return.

The first type is the direct return for A_1, generated by how the firm uses the resource at t_0 (150). The return generated when the resource is used by firms A_2–A_5 at t_0 is the second type. A proportion of the resource is reused by A_1, after it has passed through A_2–A_5 in the initial round, creating a third type of return for firm A_1 at t_1–t_∞. Similarly, the last and fourth type of return is that which is generated by the proportion of resources that are used by firms A_2–A_5 at t_1–t_∞.

More formally, with:

E_i: efficiency of resource use (return created per resource used) of firm i at time 0
p: percentage of recycled resources that are passed on to the next firm (assumed to be constant)
n: number of firms
R_{ij}: return generated by firm i at time j
X: resources used by firm A_1 at t_0

The return generated by firm A_1 at time t_o (first type) is given by

$R_{10} = X \times E_{10}$

The return generated by firms A_2–A_5 at t_0 (second type) is given by

$$\sum_{i=2}^{n} R_{i0} = \sum_{i=2}^{n} (X \times p^{i-1} \times E_i)$$

The return generated by firm A_1 at t_1–t_∞ (third type) is given by

$$\sum_{j=1}^{\infty} R_{1j} = E_1 \times X \times \sum_{j=1}^{\infty} p^{n*j}$$

and finally, the return generated by firms A_2–A_5 at t_1–t_∞ (fourth type) is given by

$$\sum_{k=2}^{n} \sum_{j=1}^{\infty} R_{kj} = X \times \sum_{k=2}^{n} \sum_{j=1}^{\infty} (p^{n*j+k-1}) \times E_k$$

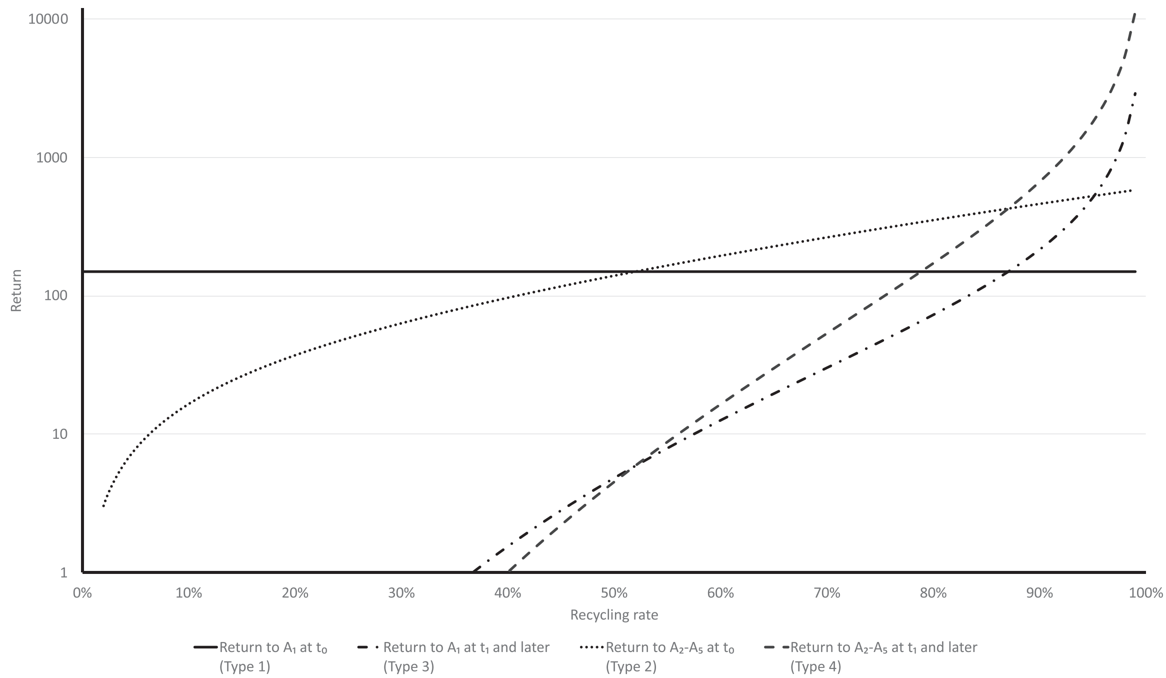

FIGURE 1 Return created by circular use of A1 resources. Underlying data for Figure 1 are available in Table F1 of Supporting Information S1

Figure 1 shows the four types of return generated by the resources of Firm A_1 in relation to the recycling rate, that is, the percentage of resources of A_1 that is passed on from A_1 to A_2 and successively from A_2 to A_3 and so forth. In our example above, we selected a recycling rate of 80%. Figure 1 incorporates a full range of recycling rates from 0% (as seen in fully linear systems with 100% waste) to 100% (as seen in perfect circular systems with 0% waste) as indicated on axis *x*.

The return (Type 1) that is generated by Firm A_1 at t_0 remains at 150 throughout. This return does not change whether resource use is linear or circular. The return that is generated by Firms A_2–A_5 (Type 2) with the resources of A_1 at t_0 depending on the recycling rate. The higher the recycling rate, the greater the return generated for Firms A_2–A_5—reusing A_1's passed on resources. This constitutes a positive externality. For fully, or perfect, circular resource use, all virgin resources are replaced by the time they reach Firms A_2–A_5, and the entire return at t_0 (600) is created with A_1's resources.

The return generated by Firm A_1 with its own resources, from periods t_1 onward (Type 3), constitutes a positive temporal externality. Strictly speaking, as the benefit is to A_1 alone, it is therefore not an externality as such. However, as the return occurs only in later periods, we refer to it as a dynamic externality. Type 4 return is generated by Firms A_2–A_5 in later periods. Again, the size of this return is positively linked to the recycling rate. This return qualifies as a positive externality in two ways: The return is created with resources of A_1 by A_2–A_5 and it is created at later periods.

In Figure 1, note how the three different positive externalities are strengthened by an increasing circular use of resources. This is the case when recycling rates are particularly high. As they increase, the positive externalities accelerate exponentially—as seen on the right hand side of Figure 1. Put differently, for low recycling rates the sustainable value approach as used for linear resource use is still a good approximation to gauge the value that is created by efficient resource use. When recycling rates are high the positive externalities created by circular resource use exceed the direct benefit to A_1 by a large margin. Thus, to an extent, using sustainable value in its linear form to determine better resource allocation would be misleading.

A frequently discussed strategy to increase eco-efficiency is to narrow resource flows (Bocken et al., 2016), that is, to reduce the amount of resources used to create the same return: The eco-efficiency of the firm, as a resource user, increases as it narrows its resource flow. Consequently, sustainable value of the firm also increases. Whilst the sustainable value of the resource reflects the value created for the specific firm in question, reducing the resource flows in this way—and where the firm passes at least some proportion of its resources onto other firms for reuse—reduces the extent to which positive externalities are created.

Figure 2 shows the return that is generated with the resources of A_1 by Firms A_1 and Firms A_2–A_5 at t_0, and by the same firms at t_1–t_∞, when A_1 passes on a proportion of its resources but in the context of the firm having narrowed its resource flow. This is, for example, the case when a firm increases its operational eco-efficiency, that is, the efficiency with which it uses its natural resources; fewer resources are needed to achieve the same return. In this way, Firm A_1 becomes more efficient and the sustainable value, not shown in Figure 2, increases. However, the consequence is that the returns for Firms A_2–A_5 decline. In other words, the more A_1 seeks efficiency by narrowing its resource flow, the more the positive externality created by A_1 for the benefit of A_2–A_5 decreases. Firms A_2–A_5 must increasingly replace the resources of A_1 that had been available,

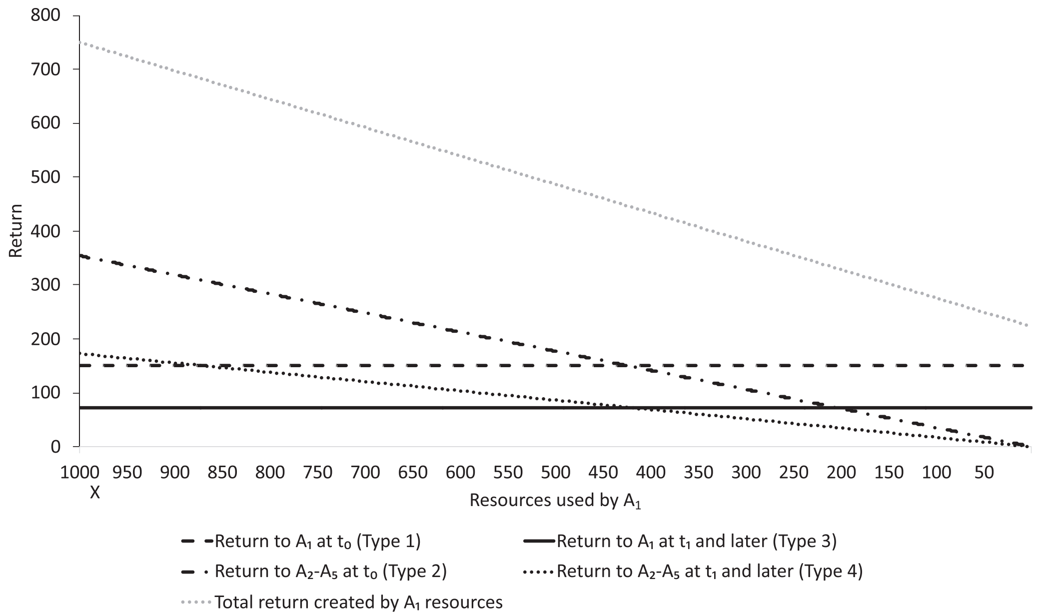

FIGURE 2 Returns created with A1 resources. Underlying data for Figure 2 are available in Table F2 of Supporting Information S1

with virgin resources. The net effect created by the dynamic externality for Firm A_1 is, however, also constant. Whilst fewer resources being looped back to A_1 in later periods can be seen as a negative effect, it is counterbalanced by the positive effect of a more efficient use of resources. Figure 2 indicates this at point *x* where resource use equates to 1000: The most value is created with the resources of Firm A_1, when A_1 uses the most resources. But *x* also represents the point at which the resource use of Firm A_1 is at its least efficient.

4 | DISCUSSION

Resources need to be used efficiently to be used sustainably. Eco-efficient resource use is a necessary but not sufficient condition for sustainable resource use. In the linear economy a more efficient use of resources by an individual resource user, such as a firm, also contributes to the more efficient use of a resource overall. This article casts doubt on this certainty when resource use is circular.

In this paper, we assess the value that is created by a more eco-efficient use of resources in monetary terms (Figge & Hahn, 2004, 2005). The more eco-efficient the use of a resource compared to its alternative uses, the more value is created. However, we also demonstrate that this principle fails when resource use is circular and we argue that this extends to most, if not all, efficiency-based indicators. This is primarily due to the scope of its assessment. We identify three kinds of externalities that fall outside the scope of existing indicators. Eco-efficiency indicators that focus on operational efficiency by including resource use and value generation within the boundaries of the resource user cannot capture these externalities caused by circular resource use.

In the financial markets, it is typically assumed that by investing in companies that create shareholder value, investors contribute to a more efficient use of capital, representing a better allocation of economic capital (Rogério, 1995; Tobin, 1984). Analogously, allocating resources to firms with a higher eco-efficiency that are thus considered value creating should encourage a greater extent of resource use efficiency. We show that under certain circumstances, that is, when resources are used circularly, firms with a negative sustainable value still contribute to a more efficient use of resources.

This, of course, assumes that the organization of circular systems—and just as importantly, assessments of eco-efficiency—pivot on groups of resource users (e.g., firms), rather than on the activities of individual firms per se. To an extent, this is what Figge et al. (2021) emphasize without addressing the issue in more detail. As our main contribution, we conceptualize the benefits of circular resource use as externalities: We not only identify their existence, but we also assess the importance of returns and externalities in circular systems.

We identify four different kinds of returns that the use of a resource creates. On the one hand they depend on "where" a return is created and on the other hand "when" the return is created. This distinction leads to three different types of positive externalities (Table 6). One of the returns—to the initial resource user during the initial time period as indicated in the upper left hand quadrant—occurs regardless of whether resources are used linearly or circularly. It is this return that is typically captured by eco-efficiency indicators and assessment techniques to date. The other three returns (shaded areas in Table 6) can be considered externalities. They are either not addressed at all by existing indicators and assessment techniques, or only partially so.

TABLE 6 Positive externalities of circular resource use

		Where return is generated	
		Original resource user (A_1)	**Subsequent resource users (A_2–A_5)**
When return is generated	**Same** period (t_0)	Linear resource use	Systemic static externality
	Later period (t_1–t_∞)	Idiosyncratic dynamic externality	Systemic dynamic externality

We argue that these three returns are specific to the circular economy and describe the contribution of the circular economy to using resources more efficiently. As the resource user that initially uses the (then) virgin resource does not benefit from this use, subsequent returns can be considered to be (positive) externalities (Pigou, 1921): We consider any return that occurs outside the scope, geographical and/or temporal, an externality of the initial resource use.

Externalities complicate decisions and have policy implications. In the context of sustainability, we typically discuss negative externalities. When resource users use resources (more) circularly by sharing resources, they create positive externalities. As a result of externalities the receiving resource users do not have full control over the resources they use. When decision-makers are self-interested and rational, it is only under very restrictive assumptions that optimal decisions will automatically ensue in the presence of externalities (Coase, 1960). We can expect externalities to lead to market failure (Bator, 1958). In the case of negative externalities, policy makers use, for example, command and control measures, permits or taxation to correct for the detrimental effect of externalities (Sterner & Coria, 2012). The presence of positive externalities created by circular resource use might require a similar intervention of policy makers. In the absence of these interventions, an eco-efficient linear resource use is likely to be more incentivized than an eco-efficient circular use of resources. As we have shown, a more efficient linear resource use can be detrimental to the eco-efficiency of resource use overall. Put provocatively, the externalities that we identify point to the need of regulation of the circular economy. This also applies, if using resources circularly is profitable. Unregulated market forces will not suffice to fully unearth "an economic opportunity worth billions" (Ellen MacArthur Foundation, 2013) but it will take regulations to do so.

A specific limitation of our research is that we do not consider the time value of the returns that are generated by resources. It has been argued for centuries in financial decision-making that money has a time value, that is, that receiving money earlier is preferred to receiving money later (Alamad, 2019). Future returns are therefore typically discounted to reflect present day values. Whether discounting future returns is in line with intergenerational equity—and is therefore sustainable—is subject to debate (Isacs et al., 2016; Markanday et al., 2019). We do not believe this to be a major concern in this context here for two reasons. The time value of money can be, as it is currently the case in many markets, very low and the discounting effect would only be significant when the circularity process is very slow. Whilst we are interested in the total return generated by resources rather than the value of the returns to the present generation, further research could nevertheless try to introduce discounting into future models.

Our model furthermore assumes that the resources of a single resource user are used circularly; we assumed this to isolate the effect of circularity from other effects. Resource use in practice is more complex. Further research could look into the overlapping effects when the resources of several resource users are used in an imperfectly circular way.

To conclude, the circular use of resources can increase the eco-efficiency of resource use. When resource users increase the circularity of resource use by sharing resources they create positive externalities. Existing indicators and assessment techniques focus on operational eco-efficiency, that is, the efficiency of resource use within the immediate scope of resource users, and therefore fail to capture the benefits of circular resource use. Existing indicators and assessments must be adapted accordingly if they are to capture the benefits of circular resource use and to help decision-making for a better use of natural resources.

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DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

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