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ReTraCE

Realising the **Tr**ansition to the **C**ircular **E**conomy

Deliverable 3.3

Models and Methods for Assessing CE Economic Efficiency

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Authors: Akis Bimpizas, Emilija Bozhinovska, Andrea Genovese, Benjamin Lowe, Wasim Malek, Mario Pansera, Josep Pinyol, Mohammad Javad Ramezankhani

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Executive Summary

- The report reviews the conventional definitions of economic efficiency and their application to the notion of Circular Economy.
- The report shows that economic efficiency is an essentially contested notion. Its conventional definition and application are directly connected to the dynamics of market-based capitalism.
- The application of the notion of economic efficiency developed to assess market-based economies is insufficient to take into account the social and environmental dimensions that are needed to realise a transition to a CE.

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1. Introduction

The calls for a transition towards a Circular Economy (CE) are accompanied by claims about the efficiency in resources consumption that circularity implies. The Ellen MacArthur Foundation's definition of a CE for instance, emphasizes the need to decouple economic activity from the consumption of finite resources, removing the concept of waste itself, and supporting the transition with the adoption of renewable energy (The Ellen MacArthur Foundation, 2017). Such an approach is based on the assumption that a CE would be, almost by definition, 'more efficient' than linear economy. Nevertheless, most of CE's literature is often too narrowly focused on notions such as resource-efficiency, energy-efficiency or, more commonly, eco-efficiency. A broader conceptualisation of economic efficiency for CE is still missing. This is probably due to the fact that economic efficiency is a notion that is highly contested itself. In conventional economic theory, the discussion of the desirability of a social policy of a particular economic policy or, more generally, of a specific model of organisation of the economy is based on the concepts of rationality and efficiency. However, it is important to remember that rationality and efficiency are not absolute concepts. Their meaning is highly dependent on the context and on the objectives to be pursued within that context. A certain tool can be efficient with respect to the pursuit of particular objectives and being completely inefficient with respect to different objectives. Moreover, the CE itself is an essentially contested notion that is likely to shelter multiple meanings and political agendas (Korhonen et al., 2018). As a result, despite allegations of the political neutrality that characterise a great deal of the literature about economic efficiency, its combination with a highly contested notion such as the CE is likely to produce just as much controversy.

The aim of this report is to review the main ideas underpinning the conventional definitions of economic efficiency and to critically discuss its implications in the context of the CE. The main conclusion of this report is that the notion of efficiency is a basic notion of how market-based capitalism should be evaluated. However, this notion has failed to incorporate environmental and social dimensions into the evaluation of the economic system, leading to an unprecedented environmental crisis and economic inequality. The transition towards the CE and the reformulation of how the economy has to work is an opportunity to open up the debate on what are the priorities of the CE and the appropriateness of efficiency within this set of priorities. Such a debate might also potentially overcome "efficiency" as a main indicator of the performance of economic systems.

The report is organised as it follows. First, we discuss how economic efficiency is framed in the existing scientific literature. Second, we review the main methods to measure efficiency that are usually associated with CE. Finally, we provide some reflections about the contested nature of economic efficiency.

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2. Economic Efficiency and the Circular Economy

The following sub-sections provide an overview on the definition of economic efficiency in the context of the transition to the Circular Economy. Also, a brief review of methods and approaches employed to measure economic efficiency in a CE context is presented

2.1. How economic efficiency is defined in the Circular Economy literature

Traditionally economic efficiency definitions draw on notions of Pareto Efficiency and welfare-maximisation or more advanced concepts, such as the Kaldor-Hicks condition (Farrow, 1998). These definitions share two basic principles. First, economic efficiency implies a state of equilibrium in which it is impossible to improve the situation of one party without imposing a cost on another (Pareto equilibrium) (Markovits, 2008). Second, economic efficiency represents a situation in which a society is getting maximum net benefits from an activity or its scarce resources; this can be represented in different forms, including minimising costs, maximising revenues/profits, or maximising utility (Mankiw, 2012). As Bauwens et al. (2020) indicate, "economic efficiency is the degree to which a scenario allocates economic resources to produce the highest welfare while minimising costs". This is also the basic idea underpinning conventional economics based on the neoclassical theory of equilibrium.

In search of the frequently used definition of economic efficiency in the context of the CE, an initial scan was performed, in order to retrieve existing literature (published in peer-reviewed journals) debating the concept of economic efficiency in the context of a circular economy. The search used key terms such as "circular economy" and "economic efficiency" on Web of Science (WoS) and Scopus which returned 24 and 26 papers respectively. Thereafter, duplicated and non-English papers were removed. Also, papers that were irrelevant to the context of the CE were removed following an analysis of their abstracts and introductions. Consequently, 19 papers were left to be review. The outline of this review is shown in Table 1.

The results show that the literature on this topic is scarce. While there are three articles that do not define or even mention what they mean by economic efficiency, the rest of the studies translated economic efficiency to some sort of economic increase in level of outputs, GDP, income, profitability, sales revenue, and return on investment, or decrease in costs or energy loss. This highlights the point that scholars use "increase in economic efficiency" as a replacement term for profit/revenue/income maximisation or cost minimisation, and it is not only limited to CE literature. The definition of economic efficiency in the field of the CE does not neither substantially challenge nor even use the formulation of Pareto Efficiency that constitutes the core of neoclassical economics.

Review of these articles shed light on the fact that economic efficiency assessment of CE lacks conceptual framing, especially at macroeconomic level. Only five papers established conceptual work

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on the concept of the CE, among which two conducted bibliographic reviews and out of the other three, only one of them explicitly described or pointed at the definition of economic efficiency.

Table 1 – Definitions of economic efficiency in the context of the CE

#	Study	Context	Region	Empirical/Conceptual	Economic Efficiency Definition
1	(Babu et al., 2020)	Agriculture	Central Asia	Empirical	Increase marginal financial returns
2	(Sánchez-Ortiz et al., 2020)	-	-	Conceptual	-
3	(Zhao et al., 2019)	Eco-industrial Park	China	Empirical	Increasing the level of outputs
4	(Plastinina et al., 2019)	Waste Management	Russia	Empirical	Increase in outputs, Decrease in costs
5	(Giama et al., 2019)	Resource Efficiency	-	Conceptual	-
6	(Baleta et al., 2019)	Sustainable Development	-	Conceptual	Increase in GDP
7	(X. Liu et al., 2019)	Mining	China	Empirical	Increase in exported Emergy
8	(Musicò et al., 2019)	Food and Beverage	Italy	Empirical	Increase in income
9	(Cherepovitsyn et al., 2018)	Oil and Gas	Russia	Empirical	Increase in net income, net present value, profitability
10	(Moreau et al., 2017)	-	-	Conceptual	-
11	(Iraldo et al., 2017)	Energy	-	Empirical	Decrease in costs
12	(Eggert, 2016)	Production (metal)	-	Conceptual	Increase in net economic benefits
13	(Kulczycka et al., 2016)	Waste Management	Poland	Empirical	Increase in profitability
14	(Xie & Liu, 2013)	Steel Production	China	Empirical	Increase in sales revenue, profit, and economic AV
15	(Ratner et al., 2020)	Energy	Russia	Empirical	Decrease in costs
16	(Bartolacci et al., 2019)	Waste Management	Italy	Empirical	Decrease in costs
17	(Pan et al., 2016)	Eco-industrial Park	China	Empirical	Decrease in energy loss
18	(Z. Liu et al., 2016)	Eco-industrial Park	China	Empirical	Increase economic return on investment

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19	(Shengguo & Xiaodong, 2013)	Sectoral Study	China	Empirical	Increase in net economic benefits

Sánchez-Ortiz et al. (2020) conducted a bibliographic review to identify indicators used in the literature related to the CE with the specific aim of measuring the efficiency of the CE initiatives. They shed light on existing problems in defining indicators for measuring the efficiency of the CE initiatives. The most problematic issue is that it is extremely difficult to obtain data for some indicators, if not impossible. In another review, Baleta et al. (2019) focus on sustainable development in general and discuss the latest developments in energy, water and environment systems which fit the notion of CE in particular. Their study shows that currently, most of the studies only investigate the technical feasibility of the CE, while a full analysis focusing on all aspects of sustainable development is yet to be done. They also highlight the necessity of developing and using composite indicators as an overall metric of sustainable development in future researches. However, they only focus on the economic and environmental aspects of the developments in aforementioned systems. They use the term "economic efficiency" as an equivalent to "increase in GDP".

Moreau et al. (2017) propose a conceptual framework focusing on the social aspect of the CE. They argue that maintaining products and materials at the highest potential value through reuse, remanufacture or recycling means that cost-effectiveness underlies these CE activities, possibly at the expenses of lower energy intensity and higher labour intensity. The solution presented in their study suggests the need for political reform toward social rationality and shifting taxes from labour to resource consumption for a more suitable environment for human labour. Giama et al. (2019) develop a conceptual framework and introduce the circularity indicator for a product or process. The focus is placed on resource efficiency in their study; in an application of their framework, they show that a 25% increase in the recycling material used as an input material for a production process can lead to a 0.5 increase in the circularity indicator score.

In conclusion, the review shows that the literature on the CE has not only failed to engage with the neoclassical definition of economic efficiency but has also failed to provide a robust and alternative definition and conceptualisation of efficiency able to substantially challenge the conventional notion of neoclassical economic efficiency. This is an important point to address and differentiate the concept of economic efficiency from those views that merely see it from the economic perspective as maximising the net benefits. It is important in a sense that CE is a multidisciplinary concept designed to contribute to sustainable development and any kind of assessment solely from an economic point of view will lead to distorted results. Economic, environmental and social factors altogether should play a pivotal role in the CE assessment.

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2.2. How Economic Efficiency is measured in the Circular Economy

Although the literature on CE does not offer alternative or innovative framing of economic efficiency, indicators to assess performance, resource efficiency and productivity abound. These indicators are often indirectly linked to economic performance e.g., intensity indicators that link resource use or emission to GDP. In this section, with the help of Elsevier's Scopus database, a brief review is conducted for the methods that are used in the academic literature to measure economic efficiency in the CE context. Three levels of keywords are used for this literature review. At the first level, "circular economy" is combined with the second level keywords "efficiency", "effectiveness", "productivity", and "performance". These second level keywords are each combined with the third level keywords "evaluation", "measurement", and "assessment" to form a total of twelve searches in the database.[1] In total, after eliminating the duplications, 143 unique articles were identified with details shown in Table 2. The proportion of each search results is illustrated using a Venn diagram shown via Figure 1.

Table 2 – Number of articles found by searching keywords in Scopus database (October 2020)

		Second level keywords	Third level keywords		
			"evaluation"	"measurement"	"assessment"
First level keyword	"circular economy"	"efficiency"	13	40	4
		"effectiveness"	1	0	0
		"productivity"	0	0	0
		"performance"	23	7	65

After reviewing the abstract and the body of these papers, 33 papers are selected for review; the rest are excluded from this study. It is worth noting that around one third of the studies mentioned in Table 2 focus on pure engineering methods, mostly related to chemical and civil applications, and analyse data from laboratory experiments or technical simulations. In these studies, usually efficiency translates to changing the structure of products to increase profitability or decrease the emission of harmful ingredients.

The first thing that emerges from the review is that the connection between economic and resource efficiency is particularly clear in the case of 'eco-efficiency'. The concept of eco-efficiency has been introduced by the World Business Council for Sustainable Development and it aims to describe a production of economically valuable goods and services while using fewer resources and creating less waste and pollution. Its link with economic efficiency is clear since many authors directly

[1] The searches took place in October 2020 with no limitations in years of publication for the articles.

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connect the notion of eco-efficiency to win-win solutions that combine economic performance with environmental goals. For example, according to a review conducted by Huang et al. (2018), most researchers in the field essentially define eco-efficiency as maximising economic efficiency while minimising the negative externalities, such as environmental pollutants, waste and reducing resource consumption, including energy. Therefore, eco-efficiency is used as a measure to express how efficiently an economic activity is using nature's goods and services.

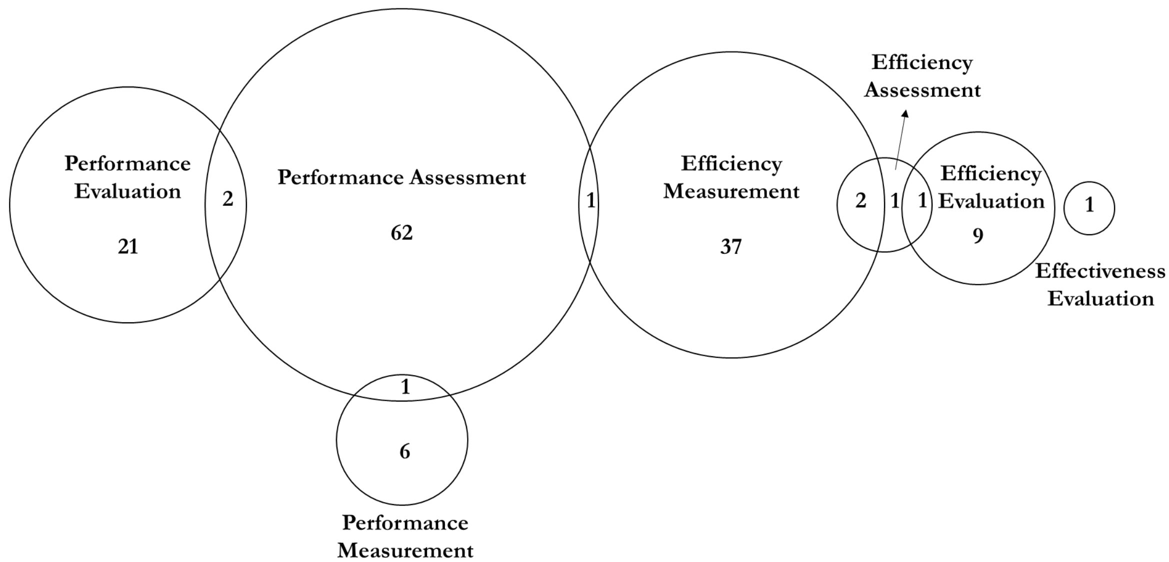

Figure 1 – Search results by keywords

In other words, eco-efficiency can be seen as a combination of resource efficiency and resource productivity (Ichimura et al., 2009). Resource efficiency focuses on increasing economic output with a given resource input (increasing resource productivity), or minimising resource input with a given economic output (decreasing resource intensity) (Stocker et al., 2015). Resource productivity is a measure of the output which can be expressed as product unit or value per unit of resource input. This measure expresses the economic efficiency in generating added value from the use of resources. Resource intensity is reciprocal of resource productivity as it represents a measure of the resources required for the provision of a unit of a good or service. It is usually expressed as a ratio between resource input and product or service units provided (CEECEC, 2010).

The logic of increasing resource efficiency and productivity is the assumption that this would lead to reduction of resource consumption, which indirectly reduces environmental impacts, while increasing the value of the produced product or service. Expressed as a plain measure, eco-efficiency is the ratio of product (or service) value to environmental impact, such as environmental load (e.g. CO2) per unit of economic activity (e.g. GDP) (Ichimura et al., 2009). In short, eco-efficiency is concerned with creating more value through an increase in resource productivity and decrease of resource intensity with less environmental impact that both can present a competitive advantage for

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businesses (Huang et al., 2018). Nevertheless, abundant and robust empirical evidence shows that increasing resource efficiency can actually accelerate the pace of resources exploitation (rebound effect) and that intensity indicators are not a good proxy to measure absolute reductions of CO_2 emissions and resource depletion (Rodriguez et al., 2020).

The concept of eco-efficiency and its related indicators of resource efficiency, productivity and intensity, are essentially expressing the environmental impact of the resource use relative to the value of output. However, the key novelty of the CE concept is to go beyond eco-efficiency and retain (or extract more) value of resources within the economy for as long as possible. Therefore, most new indicators and models for measuring the efficiency in the CE are incorporating the concept of resource circularity. At the same time the also incorporate other elements such as environmental performance, resource efficiency and conventional economics. This inclusion of measures for circularity in indicators and models, shows that the concept of CE is going beyond increasing efficiency by reducing impacts and resource use. A brief overview of the newest indicators that try to measure circularity and related elements such as efficiency or environmental impacts can be found in Appendix I.

Apart from the centrality of the notion of eco-efficiency, the review also shows that there is a variety of techniques to measure different forms of efficiency. For instance, Data Envelopment Analysis (DEA) was observed in ten studies (see Table 3); Life Cycle Assessment (LCA) in six (Angelis-Dimakis et al., 2016; Bech et al., 2019; Bracquené et al., 2020; de Souza Junior et al., 2020; Gu et al., 2020; Kerdlap et al., 2020; Schneider et al., 2019). Respectively, three studies employed System Dynamics (SD) was used (Hu & Zhang, 2015; J.Köhler et al., 2016; Kazancoglu et al., 2020) and Material Flow Analysis (MFA) (Hoehn et al., 2019; Kuisma & Kahiluoto, 2017; Voskamp et al., 2017). Simulation (Braun et al., 2018; Gaspari et al., 2017), along with Input-Output Analysis (Aguilar-Hernandez et al., 2019; W. Liu et al., 2018) and econometric models (Di Foggia & Beccarello, 2018; Y. Liu et al., 2020) were found in two papers.

Figure 2 shows the frequency and diversity of methods that were used among the selected 33 articles. It also shows the countries that were used in the case studies. China, as the pioneer country for CE studies, has the greatest number of case studies among the selected papers.

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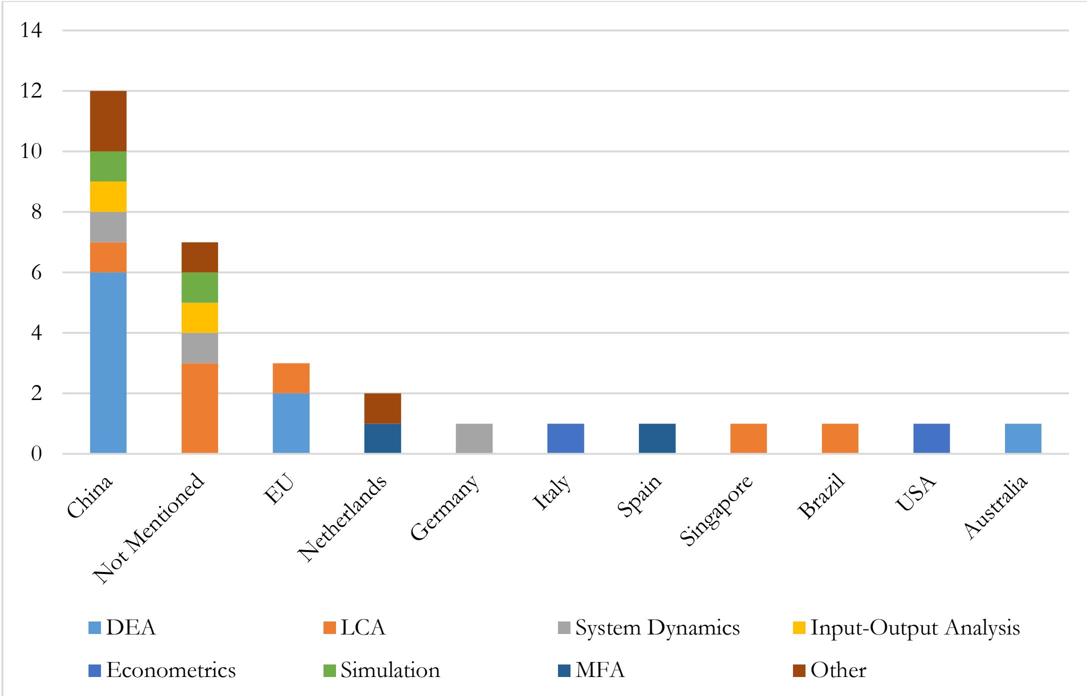

Figure 2 – Frequency and diversity of methods used and countries subjected to case studies

Figure 3 shows how many times the methods are used at each level of analysis.

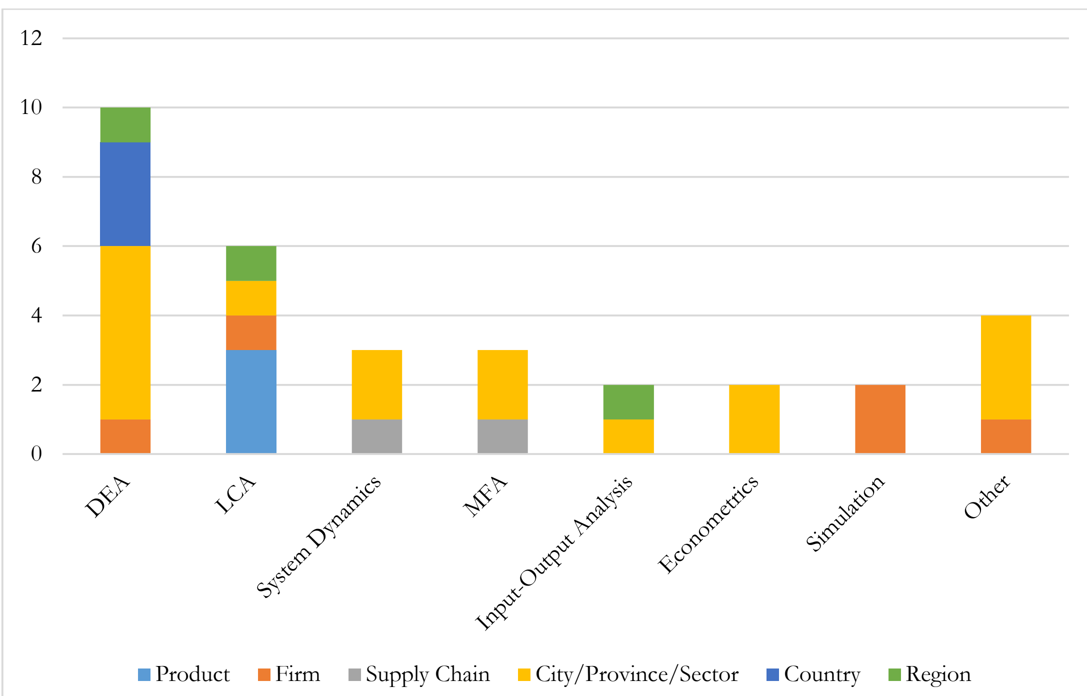

Figure 3 – Frequency and diversity of methods used in different levels of analysis

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According to Figure 3, DEA is the most commonly used method to assess efficiency across different levels related to the initiatives linked with the concept of CE. DEA is a popular nonparametric tool introduced by Charnes, Cooper and Rhodes (1978) based on the principles of production theory in economics to estimate the relative production frontier for a set of similar decision making units (DMU). In comparison with other methods, especially with econometric methods, it requires relatively less assumptions and is characterised by less computational complexity. Because of that, it has gained popularity over the past two decades and its application has extended to operations management studies to mainly be used as a benchmarking tool for performance assessment (Cooper et al., 2011). For example, in our literature review, one study uses DEA to evaluate the eco-efficiency of different subsectors in the Australian agri-food system (Pagotto & Halog, 2016) while another study focuses on ranking the European countries based on their performance in municipal solid waste management (Giannakitsidou et al., 2020).

The underlying principle behind DEA method and all its variations is the objective to maximize the outputs with trying to use less inputs. Table 3 shows the factors that are used as inputs and outputs in different reviewed studies. Apparently, different factors with different measurement units can be simultaneously used in DEA as inputs/outputs which justifies its popularity among scholars. For example, among the most commonly used outputs, one can identify that "Profit/Added Value/GDP per capita" which is measured in monetary units is used concomitantly with "Amount of wastewater", "Amount of emission", and "Amount of solid waste" which are measured in physical rather than monetary units.

Table 3 – Inputs and outputs used in DEA-based studies

Paper	Inputs													Outputs						Undesirable Outputs		
	energy consumption value	Energy (equivalent to weight of a resource)	Water consumption value	Water consumption (litres)	Capital (industrial fixed assets, land)	Labour (# of employees)	Raw materials	Industrial Wastewater Treatment Cost	Wastewater Treatment Facilities (#)	Investment in Environment Governance	Processing Cost	Social Progress Indexes (basic human needs, foundations of wellbeing, opportunity)	Municipal Solid Waste generated	Profit/Added Value/GDP per capita	Recycling (rate of water reuse)	Recycling (rate of waste recycling)	Physical Products	Customer Satisfaction	Circular Material Use rate	Amount of wastewater	Amount of emission	Amount of solid waste
(Lu et al., 2020)	×		×		×	×								×	×	×				×	×	×
(S.-L. Guo, 2015)					×	×	×										×					

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(Ding, Lei, Wang, & Zhang, 2020)				×	×	×	×	×				×	×	×				×		×
(F. Guo et al., 2016)	×											×						×	×	×
(Wu et al., 2014)		×	×	×	×							×						×	×	×
(Ding, Lei, Wang, Zhang, et al., 2020)				×	×			×							×			×		×
(Jiang et al., 2019)		×	×						×			×				×			×	
(Robaina et al., 2020)		×		×	×							×	×	×					×	×
(Giannakitsidou et al., 2020)										×	×			×			×			
(Pagotto & Halog, 2016)		×	×						×			×							×	

There are two problems with DEA-based studies reviewed in this report. One is a general problem existing in most of classic DEA studies and the other one is limited to the studies in the context of the CE. The first issue is that the classic DEA models analyse data for the past and treat each DMU as a black box without explicitly identifying the sources of inefficiency inside a DMU. Although some efforts has been done to tackle this issue with the introduction of Network DEA (Tone & Tsutsui, 2009), it increases the complexity of the model and therefore its application is limited. For example, none of the 10 papers reviewed in this report uses this variation of DEA models or any other variation that would tackle this issue. Moreover, DEA can only be used to evaluate what had been the impact of a certain policy in the past among a set of similar DMU. It offers no ex-ante analysis while it might be required if the CE-related initiatives introduce major shifts in economic structures.

The second issue with these DEA-based studies is that they often focus on economic and environmental efficiency measurement while they starkly fail to incorporate social factors in their analysis. Out of these 10 paper, only one of them uses some sort of social factor in their analysis (Giannakitsidou et al., 2020). This leaves a huge gap yet to be filled by academic studies.

Other methods including LCA, MFA, SD and simulation are usually used as a tool for resource efficiency evaluation. LCA is mainly used in the CE context at the product level to assess environmental impacts in different stages of the life cycle of a product or process. That said, Angelis-Dimakis et al. (2016) combine LCA with the concept of eco-efficiency and suggest that eco-efficiency can be calculated as the ration of total value added over total environmental impacts calculated by the LCA. MFA and SD are among the tools that are used on different scales including regional and supply chain level. They are particularly useful tools when data is insufficient for analysis (Hu & Zhang, 2015).

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For example, Voskamp et al. (2017) use MFA to analyse the urban metabolism in Amsterdam to provide a deeper understanding of urban resource management in that particular city.

Input-Output Analysis is another method that has appeared in this review while it is combined with other methods including Emergy Analysis (Liu et al., 2018) and SD (Pfaff et al., 2018). Liu et al. (2018) use a mixed method to analyse the changes in emergy structure, functional efficiency, and sustainable development capacity of a Chinese province over a period of time. With the help of this mixed methods, they measure the flow of regional energy, materials, and capital to evaluate sustainability at the regional level.

Particularly popular are methods to estimate efficiency through econometric models. Di Foggia and Beccarello (2018), for example, use an econometric model to estimate the efficiency of waste collection and disposal centres across Italy between 2013 and 2015. Based on their calculations, a potential savings per collection and disposal centre is identified and they suggest that changes in policies and tax reforms could result in total savings between €1.21 bn and €1.96 bn over the course of five years. In another study, Lu et al. (2020) evaluate the impact of recycling programs on employment in the counties of Florida state in the US between 2000 and 2011. Their study shows that an increase of 1% in recycling rates would result in 0.4% increase in job growth which runs in the face of the idea which casts environmental protection programs as slowing economic growth.

Econometric models stem from time series analysis, especially those that are linked with regression analysis. This is one of the main issues about econometric models that is highly relevant to the idea of transition toward the CE. The main problem of time series analysis is that the data for the past may not reflect what is going to take place in the future because the behaviour of the system and its agents might significantly change. This might be the case for transition scenarios toward the CE. If transition scenarios bring in seismic shifts in economic incentives, business models, technologies, policies, and consumers' behaviour then making decisions based on these models might not be relevant.

3. Critiques to the notion of Economic Efficiency

The notion of economic efficiency has traditionally been a priority for policymakers and practitioners in market-based economies. Economic efficiency is a basic principle of a market-based economy, as people exploit their gains from trade in markets maximising their available resources, leading to efficiency. As Krugman and Wells (2015) define, 'an economy is efficient if it takes all opportunities to make some people better off without making other people worse off'. The system of incentives in a free-market economy encourages economic actors to maximize the use of their resources and opportunities to improve their benefits. As economic actors are free to choose what and how to produce and consume, free competition encourages all economic actors to maximize the

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efficiency of their economic performance. Thus, improving efficiency has traditionally been perceived as the best way to contribute to the common good, as a way to optimize production and potentially minimize its environmental impact (Creutzig et al., 2018).

Nevertheless, in many cases, efficiency is not a public priority. Although efficiency has traditionally been considered a desirable outcome, markets generally lead to efficiency, but in case of market failures, the market outcome becomes inefficient. Also, there are cases where other social needs may compete or even come into contradiction with the notion of efficiency. In other words, there might be cases in which economic efficiency is not socially desirable. Moreover, the idea of efficiency has been traditionally used to boost productivity and to enable growth, paradoxically involving a net growth in demand despite its initial aim to reduce it (Ayres, 2007; Millward-Hopkins et al., 2020; Sakai et al., 2011). Krugman and Wells (2015) suggest that economic efficiency should not always be the first priority of policymakers, as efficiency is not the only principle that defines societal goals, and in some cases the notion of efficiency conflicts with alternative goals, such as fairness, equity, or sustainability.

The project of the CE is an example of a governmental intervention to deliver societal goods. It should address the failure of the markets to combine production with environmental conservation (European Commission, 2015). Different notions of efficiency have been largely evoked to evaluate the performance of several CE initiatives. However, the dominant way of framing efficiency in the context of CE is certainly the notion of eco-efficiency e.g., the capacity to maximise economic output while minimising energy, materials and waste. This is a view of economic efficiency that directly associates the imperative to deliver economic growth as a main mechanism to create common good to the need to preserve finite environmental resources. This position is also known as 'ecomodernism' (Genovese & Pansera, 2020). For Bauwens et al. (2020), the prioritisation of economic efficiency in an ecomodernist CE version would lead to further economic growth, which would require massive investments in R&D, and may enfeeble the environmental aims of the CE due to the rebound effect (Hickel & Kallis, 2019; Sorrell & Dimitropoulos, 2008; Zink & Geyer, 2017).

Many authors claim that the eco-efficiency concept, which as we showed above reflects the neoclassical principles associated with the conventional formulation of economic efficiency, will not represent a sufficient response to the challenge of sustainability for the following reasons:

1. The concept of eco-efficiency does not resolve the Jevons Paradox and does not address rebound effects. The reason is that as productivity increases, so does consumption because the capacity to consume becomes larger and the need to perpetuate growth drives the economic actors to consume more (Blake, 2005). In addition to the technological advances, important changes in social production and consumption patterns as well as political and governance organisation are needed.

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2. Indicators such as resource intensity do not reveal the qualitative aspects of the environmental impacts associated with the used resources, such as toxicity or scarcity of materials. On the denominator side expressed as an economic value, an observed decrease in resource intensity may be due to a reduction in the amount of materials used or to an increase in the economic value of the products (CEECEC, 2010; Rodriguez et al., 2020). That is, when the GDP denominator is growing faster than the resource numerator, resource intensity would decrease even though the absolute resource consumption may increase.
3. In case there is an economic recession, the GDP tends to fall faster than resource consumption, therefore the energy intensity ratio rises. On the numerator side, if resource-intensive processes are relocated abroad and highly processed goods are imported instead, and the tendency is that semi-finished and finished products are increasingly imported in developed countries, the resource efficiency indicator for the importing country would increase, while its real material footprint would increase. In this way, the resource intensity indicator would falsely show decoupling of economic growth from resource use, or simply dematerialisation, as this observation would be derived mainly due to the indicator's methodological weakness (Müller et al., 2017).

As a result of these shortcomings, a transition to CE should overcome the notion of eco-efficiency and its connection with obsession with GDP increase. According to Stahel (2019) the circular economy objective is "to optimise the use of objects, not their production; to preserve the use value of stocks of objects, components and molecules at their highest utility and value levels; and to profitably manage these stocks in competition with other economic options". Here the wealth is measured as growth in the quality and quantity of stocks, not an increased throughput as "use (or utilisation) value is the dividend we harvest without consuming the stocks themselves". Therefore, the use value of an object is higher for the owner than the sum of the value of its materials; reusing goods is more profitable and ecologic than recycling. This means that introducing economies of scale to increase productivity is irrelevant to the CE. In summary, the circular industrial economy is "counter-intuitive to manufacturing economics, small and local is now beautiful and profitable, instead of bigger and global being more profitable". It is about reproduction not growth of production and productivity. The CE leverages on care and other non-market dimensions; as such, evaluating it through market-based concepts such as efficiency might be problematic. In addition, However, maintaining the economic and resource value of the materials is not yet perceived as a priority by policymakers and economic researchers focused on efficient production and economic growth because prevention activities slow GDP growth (Hickel & Kallis, 2019).

If increasing environmental effectiveness and democratic sharing of economic benefits are the guiding principle of the CE rather than increasing economic efficiency, then in practice the CE would resemble the bottom-up sufficiency model in combination with peer-to-peer circularity described in

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Bauwens et al. (Bauwens et al., 2020). The bottom-up sufficiency model is based on decentralised and small-scale businesses that are driven by the sufficiency principle. Here the production is based on local needs to make communities self-sufficient. This bottom-up sufficiency model would entail substantial reductions in consumption patterns of consumers. However, this model is expected to trigger a period of low or negative GDP growth as it involves deliberately downscaling production and consumption, which could result in unintended social and economic instability, while being uncertain to meet the desired environmental aim. Peer-to-peer circularity model brings in a sharing economy mindset based on digitalisation and decentralisation of economic activities, in which individuals can temporarily access various kinds of resources and services on demand rather than owning them, thus becoming users rather than consumers. Therefore, trade-offs between environmental effectiveness, social benefits and economic efficiency dimensions would have to be made in order to design a mission-oriented and socially feasible CE model. Therefore, blending bottom-up sufficiency and peer-to-peer circularity principles towards the shift away from consumerist lifestyles could be a feasible avenue to pursue (Bauwens et al., 2020).

As Krugman and Wells (2015) explain, economic efficiency is a public objective that in certain contexts competes with other public priorities, such as fairness, inclusivity, or to reduce the environmental impact. These differences between models for the circular economy suggest that there is a need to open up the debate on what should be the priorities of the circular economy. Scholars in traditional and ecomodernist economics argue that efficiency should be a dominant priority for economic policy, as it has the potential to improve production methods, making products available for large populations (Jones et al., 2010) and to reduce their environmental impact within a market-based economy logic (Pretty, 2013; Turner et al., 1994). However, there are alternative visions on how public priorities should be conceptualised. For instance, some scholars argue that new priorities should be included in the political agenda to secure the integrity of the planetary system as well as universal protection of basic human dignity for all people, by using the concept of planetary justice and stressing the interests of the poor people and planet's stewardship (Biermann & Kalfagianni, 2020; Kashwan et al., 2020). Other scholars argue that the current global hegemony of the western economic discourse needs to be challenged by not only include new values and new public priorities, but by involving local communities who are able to live and organize themselves and to acknowledge the interlinks between social and economic wellbeing (Böhm et al., 2014).

Scholars have conceptualised new ways to frame the economic system to include new public priorities than efficiency. Examples of these conceptualisations are the concept of doughnut economics, where the economic system should acknowledge environmental boundaries while acknowledging societal needs (Raworth, 2017). Also, the concept of degrowth proposes to maintain welfare while reducing consumption and production (Kallis, 2011). Other scholars argue to critically reconceptualise capitalism and post-capitalism (Chatterton, 2016; Lawhon & Murphy, 2012; Shove, 2010; Vandeventer et al., 2019), to reconsider the need for economic growth as a societal good

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(Millward-Hopkins et al., 2020) or to question the presumption of neutrality of capitalism and to open up the debate on the possibility that a transition towards a sustainable economy involves a fundamental change of the capitalist system instead of changes within it (Feola, 2019; Genovese & Pansera, 2020). All these works show the blatant need to develop new conceptualisations and new frames to review how our understanding of the economic system reflects or ignores certain public priorities and societal needs, as environmental impact or social equity. In this sense, the ways how the CE is conceptualised, and its efficiency measured reflects this same system of priorities.

4. Conclusions

There is an open debate on what should be the public priorities for the CE. The way efficiency in the CE is conceptualised reflects what are the implicit values and societal priorities that a CE will involve for the economy, for the society and for the environment. Thus, paying attention to the different conceptualisations of efficiency for the CE unveils the ongoing debates and conflicts of interest behind the conceptualisation of the CE.

As explained in section 2, economic efficiency is a notion that promotes to maximize production or use of production while minimising the costs of production. This notion is one of the pillars of the conventional market-based capitalist system, as it promotes the maximisation of production without acknowledging issues as environmental impact or social fairness. The notion of efficiency plays a different role in a context of a CE, as this system does not aim to maximize production but to reduce the environmental impact of the system. Therefore, the notion of efficiency needs to be reconceptualised to fit to the new public priorities of the CE. As explained in section 3, many new methods to measure efficiency include elements, as material circularity-based indicators, life-cycle based indicators, input of materials, intensity of use of materials, efficiency during the recycling process, GHG production per unit, and many other elements. The inclusion of these elements demonstrates an attempt to conceptualise efficiency beyond financial terms to reduce the environmental impact of production.

Despite the wide innovation in the reconceptualisation of the CE, most of these conceptualisations are strictly linked to production and do not acknowledge other elements as social satisfaction, social fairness or environmental impact. In this sense, the notion of efficiency only implies improvements in production methods, while it leaves behind other social priorities. To assess the performance of the economy beyond production, several scholars suggest reconsidering the priorities of the economic system itself, opening up the debate to critically reconsider the importance of growth and to include elements as social justice, environmental thresholds, and human dignity.

In summary, the notion of efficiency is a basic notion of how market-based capitalism should be evaluated. However, this notion has failed to incorporate environmental and social dimensions to

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the evaluation of the economic system, leading to an unprecedented environmental emergency and a situation of economic inequality. The transition towards a CE and the reformulation of how the economy has to work is an opportunity to open up the debate on what are the priorities of the CE. This reformulation is highly important, as the CE runs the risk to emulate the same failures than the linear market-based economy and prioritize overproduction instead of creating a sustainable economic system if it is evaluated with the same criteria. Also, the definition of the CE represents a unique opportunity to include environmental and social criteria to evaluate its performance. We believe that the new criteria to evaluate the CE should go beyond the mere evaluation of the production process and include elements as social equity or planet's stewardship as necessary means to build a circular economy that is sustainable.

Contents of this deliverable are currently under review for publication in international journals

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Appendix I

Table 4 outlines several key aspects from the literature. 'Type' represents the type of measure, such as a single indicator or dashboard; 'Framing' attempts to decode the notion of economic efficiency that each study was based on, into elements such as resource circularity and environmental performance; 'Methodology' represents the specific techniques used such as MCDA (multi criteria decision analysis), MFA (material flow accounting) or types of indicators when a dashboard of indicators is proposed; 'Data' represents specific variables required by the methodology such as % of recycled components or volume of waste generated; and 'Application' refers to the level that the measure is intended or actually used for, such as national level or company level.

The studies in the Table 4 appeared to be based on different notions of economic efficiency. 11 of the studies included elements of resource circularity (Ellen MacArthur Foundation, 2015; European Commission, 2020a; Geng, Fu, Sarkis, & Xue, 2012; Haas, Krausmann, Wiedenhofer, & Heinz, 2015; Karlsson & Wolf, 2008; Linder, Sarasini, & van Loon, 2017; Liu, Guo, & Guo, 2019; Niero & Kalbar, 2019; OECD, 2011; Pauliuk, 2018; Wang, Hashimoto, Moriguchi, Yue, & Lu, 2012), where attention was directed towards the use of recycled or reused resources or to ensure output resources were recycled or reused. The concept of resource productivity, where emphasis is placed on, for instance, reducing resource consumption or producing more with the same level of input resources, was included in 5 studies (Ellen MacArthur Foundation, 2015; European Commission, 2020a; Geng et al., 2012; OECD, 2011; Pauliuk, 2018).

Environmental performance, where importance is given to, for example, reducing gas emissions, industrial wastewater discharge and pollution, was a prominent theme in 7 studies (Ellen MacArthur Foundation, 2015; Geng et al., 2012; Karlsson & Wolf, 2008; Liu et al., 2019; Niero & Kalbar, 2019; OECD, 2011; Pauliuk, 2018). Meanwhile, conventional economics, demonstrated by highlighting areas like stocks and efficiency, systems costs, sales of by-products and gross domestic output, was included in four studies (Haas et al., 2015; Karlsson & Wolf, 2008; Pauliuk, 2018; Wang et al., 2012).

Evidently, resource circularity was a common element in most studies. However, the other elements (environmental performance, resource productivity and conventional economics) were only highlighted in some studies. Although one study included the concept of resource longevity (Ellen MacArthur Foundation, 2015), none of the studied literature included social equity elements. This diversity of efficiency conceptions further supports the findings from the previous section, which claim that economic efficiency is a contested notion both within and outside of the CE.

A range of approaches have been adopted in the studied literature. Four methods opt for single indicators (Ellen MacArthur Foundation, 2015; Linder et al., 2017; Niero & Kalbar, 2019; Wang et al., 2012), five opt for a dashboard of indicators (European Commission, 2020a; Geng et al., 2012; Haas et al., 2015; OECD, 2011; Pauliuk, 2018), while two prefer models (Karlsson & Wolf, 2008; Liu et al.,

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2019). The variety of approaches encapsulates the trade-off between the level of complexity and the level of representativeness. The calculation of a single indicator is usually not as complex as a dashboard of indicators or a model, and the effort required to collect data and update the associated indicator is usually relatively low. However, a single indicator may not give a sufficient representation of economic efficiency in the CE, when compared to a dashboard of indicators or a model.

The reviewed methods were also designed for different levels. For instance, four methods are relevant for the product level (Ellen MacArthur Foundation, 2015; Linder et al., 2017; Niero & Kalbar, 2019; OECD, 2011), one method applied to the facility level (OECD, 2011), three methods are relevant at the company level (Ellen MacArthur Foundation, 2015; OECD, 2011; Pauliuk, 2018), two at the supply chain level (Geng et al., 2012; Karlsson & Wolf, 2008) , two at the national level (Geng et al., 2012; Wang et al., 2012) and two at the continental level (European Commission, 2020a; Haas et al., 2015).

Table 4 - Reviewed literature on attempts to apply economic efficiency indicators in CE

#	Literature	Notes
1	(Niero & Kalbar, 2019)	**Type:** Single indicator. **Framing**: Resource circularity, environmental performance. **Methodology**: MCDA (Multi Criteria Decision Analysis). **Data**: Material circularity-based indicators (material reutilisation score and material circularity indicator), and life-cycle based indicators (climate change, abiotic resource depletion, acidification, particulate matter and water consumption). **Application**: Product level, with beer packaging as a case study.
2	(Linder et al., 2017)	**Type**: Single indicator. **Framing**: Resource circularity. **Methodology**: Calculated based on the following formula: **Data**: Value of recirculated parts, and value of all parts. **Application**: Product level.
3	(Ellen Macarthur Foundation, 2015)	**Type**: Single indicator (Material Circularity Indicator MCI). **Framing**: Resource circularity, resource productivity, environmental performance. **Methodology**: Calculated based on the following formula: Where: **Data**: Level of recycled or reused materials used as input, intensity of product use compared to industry average, destination of material after use, and efficiency during the recycling process. **Application:** Product level.
4	(OECD, 2011)	**Type**: Dashboard of indicators.

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		Framing: Resource circularity, environmental performance, resource productivity. **Methodology**: Several intensity and content indicators, recycled/reused content, renewable materials content, energy consumption intensity and greenhouse gas emissions intensity. **Data**: Data requirements include variables such as proportion of recycled content in each product, quantity of product produced, weight of product, average annual energy consumption of a product unit, average annual GHG emissions per product unit. **Application**: Product level.
5	(OECD, 2011)	**Type**: Dashboard of indicators. **Framing**: Resource circularity, environmental performance, resource productivity. **Methodology**: Several intensity indicators, such as water intensity, energy intensity, greenhouse gas intensity, and water releases intensity. **Data**: Data requirements include variables such as energy consumed in the production process, energy consumed in overhead, a normalisation factor such as output/productivity, weight of releases to surface water and weight of releases to air. **Application**: Facility level or company level.
6	(Ellen Macarthur Foundation, 2015)	**Type**: Single indicator. (Company level MCI). **Framing**: Resource circularity, resource longevity, environmental performance. **Methodology**: An aggregation of MCI across all products using weights. If calculation across all products is infeasible, only reference products are used. **Data**: Level of recycled or reused materials used as input, intensity of product use compared to industry average, destination of material after use, and efficiency during the recycling process. Weightings for product mix are also needed when aggregating at company level. **Application:** Company level.
7	(Pauliuk, 2018)	**Type**: Dashboard of indicators. **Framing**: Conventional economics, resource circularity, environmental performance, resource productivity. **Methodology**: Most indicators are based on MFA (material flow analysis), MFCA (Material Flow Cost Accounting) and LCA (Life Cycle Analysis). **Data**: Indicators are included from areas such as circular economy, life cycle resource efficiency, climate and energy, and stocks and efficiency. Examples of specific indicators are material recovery rates, waste reduction and cumulative energy demand. **Application**: Company level.
8	(OECD, 2011)	**Type**: Dashboard of indicators. **Framing**: Resource circularity, environmental performance.

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		Methodology: Aggregation of facility level indicators using appropriate weightings. **Data**: Data requirements include variables such as energy consumed in production process, energy consumed in overhead, a normalisation factor such as output/productivity, weight of releases to surface water and weight of releases to air. **Application**: Company level.
9	(Geng et al., 2012)	**Type**: Dashboard of indicators. **Framing**: Resource circularity, environmental performance, resource productivity. **Methodology**: 22 indicators are included from 4 groups: Resource output rate, resource consumption rate, resource comprehensive utilisation rate and waste disposal and pollutant emission. **Data**: Indicators include output of main mineral resource, output of energy, energy consumption per unit of GDP, water withdrawal per unit of GDP, recycling rates of plastic and waste paper, total amount of SO^2 emission. **Application**: Evaluation of China's Circular Economy at an industrial park level.
10	(Wang et al., 2012)	**Type**: Single indicator (Direct Material Input DMI). **Framing**: Conventional economics, resource circularity. **Methodology**: Calculated on the following equation: **Data**: k = type of material POP = population GDP = Gross Domestic Product in U.S. dollars DMIk = DMI in tons (t) of material k RMIk = recycled material input in tons of material k **Application**: Evaluation of the resource usage of China's national economy.
11	(Geng et al., 2012)	**Type:** A dashboard of indicators. **Framing**: Resource circularity, environmental performance, resource productivity. **Methodology**: 12 indicators are included from 4 groups: Resource output rate, resource consumption rate, resource comprehensive utilisation rate and waste disposal and pollutant emission. **Data**: Indicators include output of land, output of water resource, energy consumption per unit key product, recycling rate of industrial waste, industrial water reuse ratio and total amount of industrial waste water discharge. **Application**: Evaluation of China's Circular Economy at a national level.
12	(European Comission, 2020)	**Type**: Dashboard of indicators. **Framing**: Resource circularity, resource productivity.

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		Data: Indicators are included from 10 areas, including recycling rates, waste generation, green public procurement, and innovation. **Application**: Used by the European Commission to monitor the transition towards a Circular Economy among EU members at national level.
13	(Haas et al., 2015)	**Type**: Dashboard of indicators. **Framing**: Conventional economics, resource circularity. **Methodology**: Based on material flow accounting (MFA). **Data**: Indicators include net addition to stocks, recycling within the economy, biomass, and domestic processed output, all as a share of processed material. **Application**: Applied to global economy, and the European Union (EU27).
14	(X. Liu et al., 2019)	**Type**: Model **Framing**: Resource circularity, environmental performance. **Methodology**: Combines emergy analysis with data envelopment analysis (DEA) to assess eco-efficiency. **Data**: Emergy flow indicators, such as renewable resource emergy, non-renewable resource emergy and imported emergy. **Application**: China's biggest coal mining area in Shanxi Province.
15	(Karlsson & Wolf, 2008)	**Type**: Model **Framing**: Conventional economics, environmental performance, resource circularity. **Methodology**: Method for analysis of INDustrial energy systems (MIND), which is based on mixed linear programming, to evaluate industrial symbiosis. **Data**: A variety of variables in the integrated system, including system cost, electricity production, steam discharge, waste heat and bark sales. **Application**: An integrated system in the forestry industry in Sweden that included a biofuel upgrade plant, chemical pulp mill, sawmill, and district heating system.

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