Business practice on measuring circularity of value chains

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ABSTRACT,
The concept of the circular economy has gained increasing interest from both public and private institutions, as it is expected to provide answers on vital environmental and economic issues of the 21st century, such as climate change or resource scarcity. The core idea of circular economy lies in the maximization of the longevity of resources by extending the lifecycle of goods and reintroducing used goods and resources back into the economic circle. Public as well as private authorities proposed definitions on aims, goals of circularity and key performance indicators to assess them. To incorporate circularity into organizations´ business models, effective and efficient to use key performance indicators are necessary. Even though private business, academia, and public institutions, as the European Commission, defined key performance indicators for measuring circularity, the applicability of many key performance indicators is either bound to specific business or without proven track record in private or public business. This research ought to provide insights on today's business practice in benchmarking and measuring circularity. By interviewing companies´ representatives, it brings light on the popularized KPI´s applicability, strengths, and constraints.

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Keywords
Circular Economy, Metrics, Eco-Economy, Recycling

1. INTRODUCTION

Five trends have been identified to impact the world while moving towards 2030; urbanization; shifts in global economic power; demographic change; technological breakthroughs; climate change and resource scarcity (PWC, 2016). Changes in demography and economic output is expected to lead to increasing pressure on the Worlds ecosystem, and hence impact the availability of energy and resources. This research addresses two major issues resulting from the observed trends: resource scarcity and waste production.

The demand of resource extraction has risen substantially in the 20th century; for example, by a factor of 34 for construction material; ores and minerals by a factor of 24 and fossil fuels by a factor of 12 (Schütz, 2004). The Sustainable Europe Research Institute (SERI) estimates that in a business-as-usual scenario the demand for worldwide resource extraction of metals and minerals could grow by a factor of 1.8 from 1980 till 2030 (Giljum, et al., 2009)

While demand for resource exploitation is steadily increasing, the European Union is having the worlds´ highest net imports, indicating a large resource dependence on exporting countries. Abiotics were identified to occur rarely on EU territory as "after more than 1000 years of mining, Europe has largely depleted its primary metal sources" (Hagelüken, 2007). Data from (Eurobarometer, 2011) indicates that the material costs account for 40-45 percent of the European Unions´ gross production value. Nevertheless, the EU is recycling 55 percent out of the produced waste only (Eurostat, 2019); especially the recycling rate of e-waste in the European Union is especially low, being 41 percent compared to Japans 75-89 percent (De Groene Zaak, 2015). As demand for resource exploitation increases, the process of reusing used materials will become more attractive.

Academic interest is increasing into addressing this issue. The transition from a Linear Economy model to a Circular Economy model, in which resources should reenter into economic processes at the end of their life cycle, forming a closed-loop economic model (Ghisellini, 2016). Adopting a circular economy approach could generate an additional 4.5 trillion US-Dollar economic output by 2030 (Lacy & Rutqvist, 2015).

In order to transition towards a circular economic model and make circular business models financially viable and sustainable, private as well as public organizations need standardized tools to measure and assess circular business models.

Private as well as Public institutions have defined key performance indicators, which ought to quantify circular business processes. Still there is little known on concrete practical applications of KPI´s. In order to identify the viability and effectiveness of popularized KPI´s following research questions have been formulated.

RQ1: What measurement techniques are effectively applied by organizations to measure the circularity of their value chains?

RQ1.1: What is the discrepancy between the academic field and business practice on measuring the circularity of value chains effectively?

RQ1.1.1: If existent, what are the factors contributing to discrepancies?

2. THEORETICAL FRAMEWORK

This chapter provides partly an answer to RQ 1.1, as it discusses current academic progress on defining and measuring circularity. It on what is known about the circular economy, and present different approaches on how leading researchers intend to address the transition towards a circular economy.

2.1 Defining circular economy

Mankind gained outstanding benefits of what is called the Linear Economy, where the main objective is to transform virgin resources from mines to goods and services providing value to the consumers. It requires continuous throughput of resources in order to generate value, as competitiveness is only achieved by higher economies of scale. During this process, resources are continuously depreciated in value, and require them to be scrapped as soon as the cost of reuse or repair exceed the value of the depreciated resource (Charter, 2019)

The concept of circular economy and transitioning towards it was introduced centuries ago, as for example a well-known quote of August Wilhelm von Hoffmann (1848) states: "in an ideal chemical factory there is, strictly speaking, no waste, but only products. The better a real factory makes use of its waste, the closer it gets to its ideal, the bigger is the profit". More known concepts are the 3R principle (reduce, reuse, recycle), cradle-to-cradle, regenerative design or natural capitalism (Pauliuk, 2018) The MacArthur Foundation provided a frequently cited and well accepted definition on circular economy: "a circular economy is gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital". Opposed to linear economy Cheng states that circular economies´ "objective is to perceive resources as stocks, which need to be managed to maintain their value as long as possible". This is done by allowing the resources to reenter a life cycle by repairing, refurbishing, or repurposing resources (Cheng, 2017)

Due to the missing consensus with regard to the definition of CE, unclarity exists with regard to the methods and goals of CE. For example, reduce from the 3R strategy may refer either to waste production, energy consumption, green design or product consumption. Cheng proposed an extension to the 3R concept by introducing nine more steps, which ought to portray a more complete set of actions needed for an economy to become circular.

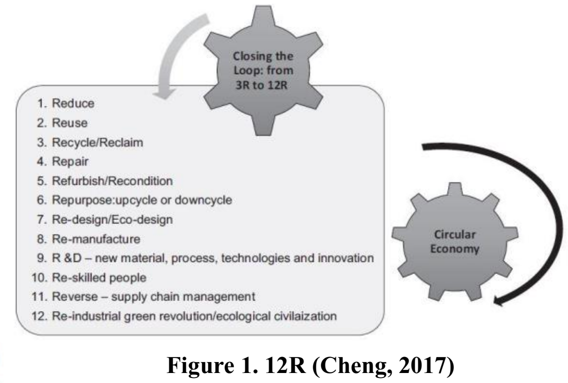

Figure 1. 12R (Cheng, 2017)

2.2 Theoretical model

In the recent years, scholars and businesses have increased their engagement in developing metrics and assessment tools to measure circularity of businesses, supply chains, cities, or continents.

Metrics assessing circularity often very in the units of analysis and scope they aim to measure, which result in differences with regard to granularity and completeness of measurement. By proposing definitions on both units of analysis and scope, Moraga aimed to classify, and hence allow to compare developed metrics (Moraga, Sophie, & Fabrice, 2019).

At first, Moraga proposed 6 strategies (units of analysis) out of which 5 have been used in this research: function, product, components, materials and embodied energy.

Metrics aiming to measure **function** of products or services the function provided by circular business models, such as sharing platforms or PPS is preserved.

Metrics aiming to measure **product** assess to what degree durability, reusability, restorability, refurbishment, or re-manufacturability is preserved or enforced.

Metrics aiming to measure **components** assess to what degree components of a product or service can be reused, recovered or repurposed.

Metrics aiming to measure **materials** assess to what extend materials are preserved through recycling or downcycling.

Metrics aiming to measure **embodied energy** assess to what extend energy is recovered or preserved at incineration facilities and landfills.

To define the well accepted concept, the Life Cycle Thinking approach was used and classified into three levels: micro, meso and macro.

Micro: indicators, which target units of analysis being present at an organizational level. The measurement data is fully extracted from the organization itself, excluding data from both, parties upwards as well as downwards the value chain.

Meso: Indicators, which target units of analysis being present at a supply chain level. Hereby data is collected from agents acting downwards, such as suppliers, as well as upwards (clients, users, recycling agencies) the value chain.

Macro: Indicators, which target units of analysis being present at a global level. Hereby, data is evaluated on causes and effects units of analysis have on actors acting outside of the organizations direct value chain, such as environment, society or economy.

2.3 Key performance indicators

Every organization, whether public or private requires to find and define its purpose of existence. The purpose of every organization is then translated into business objectives, according to which an organizations strategy is formed. In order to make judgements on the performance an organization achieves its´ objectives key performance indicators are used.

Key performance indicators (KPI`s) are a well-researched subject in management studies. While many researchers agree on KPI´s being significant for organizations for efficient and effective management, the question on what should be measured and how is constantly debated *(Neely A. , The evolution of performance measurement research: Developments in the las decade a research agenda for the next, 2005) (Neely & Keenerly, 2002)*.

According to *(Neely, Gregory, & Platts, Performance measurement system design: A literature review and research agenda, 1995)*, performance measurement is the “the process of quantifying the efficiency and effectiveness of past actions”. The process commonly includes measures and indicators, out of which the most fundamental ones are called KPI´s. Lo-Lacano-Ferreira, Capuz-rizo and torragosa-lopez claim that KPI´s “are indexes used to evaluate the crucial factors related to a defined goal” *(Lo lacano Ferreira, F. Capuz-Rizo, & Torregosa-López, 2017)*.

2.3.1 Characteristics of KPI´s

Researchers defined characteristics, which KPI´s need to fulfill, in order to become meaningful to an organization.

Hudson et al defined seven characteristics of performance measures. KPI´s should be: (1) derived from strategy; (2) be clearly defined with an explicit purpose; (3) be relevant and easy to maintain; (4) be simple to understand and use; (5) provide fast and accurate feedback; (6) link operations to strategic goals; (7) stimulate continuous improvement (Hudson, Smart, & Bourne, 2001). Established and well accepted criteria are the SMART criteria, i.e. Specific, Measurable, Achievable, Relevant and Time bound (Doran, 1981).

3. RESEARCH DESIGN

In order to perform the research, the sequential exploratory strategy was chosen, which combines qualitative- and quantitative data collection (Damian & Chisan, 2006). At first, secondary data was collected to identify current measurement techniques to measure circularity. The collected data on metrics was then classified according the unit of analysis it aims to assess and its scope. This was followed by gathering quantitative data by using semi-structured interviews to illustrate the discrepancy between organizations practices applied and what is proposed by literature. A semi-structured interview is defined as a form of interview in which the key issues, themes and topics are predefined by the interviewer. However, the order of questions can be modified, and the questions extended depending on the development and direction of the interview. The choice for this method has been made as it allows unexpected information to be collected during an interview, while, at the same time, allowing comparison of responses. (Wisker, 2007)

3.1 Data collection

This section discusses how and under what criteria metrics have been chosen for this research.

3.1.1 Qualitative data collection

Peer reviewed literature was identified using bibliographic literature search using Elsevier Scopus and search engine with full text available. The Following keywords have been used: “circular AND economy AND metric OR measurement OR indicator”. Only-full text available papers are included This search resulted in N=737. To reduce the amount of literature considered and remain relevancy, literature published within the year 2010-2020 and having at least 50 citations have been chosen, which resulted in N=5. First degree forward and backward snowballing yielded N=10. The data extraction was made by reading the literature and extracting the concept of the relevant metric and its´ corresponding parameters and calculation method.

Step 1: Bibliographic literature search using Elsivier Scopus and search service N= 737

Search Criteria

Keyword is applied to title, abstract and keyword papers:

Keywords search phrase “circular AND economy AND metric OR measurement OR indicator”.

Year range: 2010-2020

Document is in the English, German or Polish language.

Full text is available

Step 2: Filtering papers exclusion was made by excluding papers having less than 50 citations N=29

Search of papers providing a quantitatively expressed CE metric, N =5

Step 3: First degree snowballing forward and backward.

Search for papaers providing a quantitively expressed CE metric N=10

Step 4: Data extraction

Each paper has been read personally. Thereafter, the main concept design of the metric was extracted with its parameters and calculation.

Figure 2. Desk research method

3.1.3 Quantitative data collection

Qualified respondents were defined as employees working in the manufacturing or construction sector, in an organization applying- or aiming to apply- circular economic business models. The respondents should either be involved in the strategic development of circular business models or it´s operative field.

Prior to contacting the respondents, interview questions were formulated to first categorize the organization and thereafter extract data on applied measurement techniques. The interviews are held via online video chat software, like Skype or Microsoft teams, or via phone. During the interviews, a transcript is made. Prior to publishing the results, interviewees receive the transcript of the corresponding interview and results in order to confirm their correctness and completeness.

After conducting the interview with the first respondent of company A, further respondents were asked to make statements on the performance of used metrics within the organization. The respondents were asked to value each metric according to the SMART criteria using a 7-point likert scale.

4. RESULTS

4.1 Metrics identified from literature

In this section, metrics are presented and evaluated according to criteria discussed in section 3.1.1. After presenting all metrics to the respondents, the respondents indicated that following metrics are in use within their organization: CIRC, EDIM, RC, EVR, MCI, CPI, Longevity, and VRE. Other metrics were not known or used by the participating companies.

	Metric	Title	Citations	Func.	Prod.	Comp.	Mat.	Energ.	Scope
1	Edim	Vanegas, P., Peeters, J.R., Cattrysse, D., Tecchio, P., Ardente, F., Mathieux, F., Dewulf, W., Duflou, J.R., 2018. Ease of disassembly of products to support circular economy strategies. Resour. Conserv. Recycl. 135, 323–334.	56		X	X	X	X	0
2	CR	Graedel, T.E., Allwood, J., Birat, J.-P., Buchert, M., Hagelüken, C., Reck, B.K., Sibley, S.F., Sonnemann, G., 2011. What do we know about metal recycling rates? J. Ind. Ecol. 15, 355–366	425				X		0
3	RC	Graedel, T.E., Allwood, J., Birat, J.-P., Buchert, M., Hagelüken, C., Reck, B.K., Sibley, S.F., Sonnemann, G., 2011. What do we know about metal recycling rates? J. Ind. Ecol. 15, 355–366	425				X	X	0
4	EOL-RR	Graedel, T.E., Allwood, J., Birat, J.-P., Buchert, M., Hagelüken, C., Reck, B.K., Sibley, S.F., Sonnemann, G., 2011. What do we know about metal recycling rates? J. Ind. Ecol. 15, 355–366	425	X					0
5	RIR	Graedel, T.E., Allwood, J., Birat, J.-P., Buchert, M., Hagelüken, C., Reck, B.K., Sibley, S.F., Sonnemann, G., 2011. What do we know about metal recycling rates? J. Ind. Ecol. 15, 355–366	425				X		0
6	OSR	Graedel, T.E., Allwood, J., Birat, J.-P., Buchert, M., Hagelüken, C., Reck, B.K., Sibley, S.F., Sonnemann, G., 2011. What do we know about metal recycling rates? J. Ind. Ecol. 15, 355–366	425				X		0,1
7	Long.	Franklin-Johnson, E., Figge, F., Canning, L., 2016. Resource duration as a managerial indicator for Circular Economy performance. J. Clean. Prod. 133, 589–598	82		X		X		1
8	MCI	EMF. (2015). Circularity indicators an approach to measuring circularity. Ellen macarthur foundation. doi:https://doi.org/10.1016/j.giq.2006.04.004	86		X		X	X	1
9	PLCM	Linder, M., Sarasini, S., van Loon, P., 2017. A metric for quantifying product-level circularity. J. Ind. Ecol. 21, 545–558	101		X	X	X		2
10	CPI	Huysman, S., De Schaepmeester, J., Ragaert, K., Dewulf, J., De Meester, S., 2017. Performance indicators for a circular economy: a case study on post-industrial plastic waste. Resour. Conserv. Recycl. 120, 46–54	90				X	X	2
11	CEI	Di Maio, F., Rem, P.C., 2015. A robust Indicator for promoting circular economy through recycling. J. Environ. Prot. (Irvine, Calif) 06, 1095–1104	72				X		2
12	VRE	Di Maio, F., Rem, P.C., Baldé, K., Polder, M., 2017. Measuring resource efficiency and circular economy: a market value approach. Resour. Conserv. Recycl. 122, 163–171	59				X		2
13	EVR	Scheepens, A.E., Vogtländer, J.G., Brezet, J.C., 2016. Two life cycle assessment (LCA) based methods to analyse and design complex (regional) circular economy systems. Case: making water tourism more sustainable. J. Clean. Prod. 114, 257–268	135				X		2
14	CIRC	Pauliuk, S., 2018. Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations. Resour. Conserv. Recycl. 129, 81–92	109				X		1
15	TRP	Pauliuk, S., 2018. Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations. Resour. Conserv. Recycl. 129, 81–92	109		X	X			1
16	LMA	Pauliuk, S., 2018. Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations. Resour. Conserv. Recycl. 129, 81–92	109				X		1

Table 1. Desk research

4.1.1 Ease of disassembly (EDIM)

The focus of Ease of Disassembly Metric EDIM (Vanegas, et al., 2018) is the measurement of the disassembly time and the related costs, while increasing the economic feasibility of the product lifetime extension. Product lifetime extension strategy, i.e., repair, reuse and product harvesting for component reuse, requires facilitated access to product components. It is crucial to disassemble components from products without destroying for the purpose of reuse and remanufacture in favor of environment and supporting circular economy. A reduction in disassembly time cuts down costs of these activities significantly, and it can be preferred for remanufacturing or component reuse over recycling or disposal, which is environmentally beneficial.

$$\text{eDiM} = \sum_{i=1}^{i=n} (Tool\ Change_i + Identifying_i + Manipulation_i + Positioning_i + Disconnection_i + Removing_i)$$

4.1.2 *Recycling rate*

The recycling rate (Graedel, et al., 2011) describes the ratio between recycled material and the total material used.

$$\text{RC} = \frac{j + m}{a + j + m}$$

4.1.3 *Longevity*

Longevity (Franklin-Johnson, Figge, & Canning, 2016) metric is a performance-based metric, which measures contribution to material retention based on the amount of time a resource is kept in use. The measure is composed of three generic components: initial lifetime, earned refurbished lifetime and recycled lifetime.

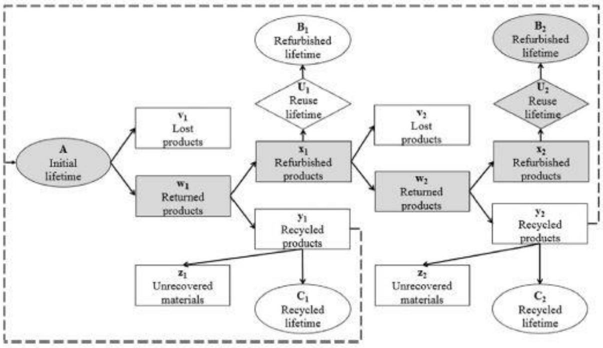

Figure 3. (Franklin-Johnson, Figge, & Canning, 2016)

$$\text{Longevity} = \text{A} + \text{B} + \text{C}$$
$$\text{B} = (\text{B}_1 + \text{B}_2)$$
$$\text{B}_1 = (\text{w}_1 * \text{w}_2 * \text{U}_1)$$
$$\text{B}_2 = (\text{w}_1 * \text{x}_1 * \text{w}_2 * \text{x}_2 * \text{U}_1)$$
$$\text{C} = \text{C1} + \text{C2}$$
$$\text{C1} = (\text{A} + \text{B1} + \text{B2}) * \frac{(\text{w}_1 * \text{y}_1 * \text{z}_1)}{(1 - \text{w}_1 * \text{y}_1 * \text{z}_1)}$$
$$\text{C2} = (\text{A} + \text{B1} + \text{B2}) * \frac{(\text{w}_1 * \text{x}_1 * \text{w}_2 * \text{y}_2 * \text{z}_2)}{(1 - \text{w}_1 * \text{x}_1 * \text{w}_2 * \text{y}_2 * \text{z}_2)}$$

4.1.4 *Material circularity indicator (MCI)*

The Material Circularity Indicator (Ellen Macarthur Foundation, 2016) measures the extent to which linear flow has been minimized and restorative flow maximized for its component materials, and how long and intensively it is used compared to similar industry-average product. Essentially it is constructed from a combination of three product characteristics: the mass V of virgin raw material used in manufacture, the mass W of unrecoverable waste that is attributed to the product, and a utility factor X that accounts for the length and intensity of the products´ use.

$$V = M(1 - F_R - F_U)$$
$$W_0 = M(1 - C_E - C_U)$$
$$W_C = M(1 - E_c)C_R$$
$$W_F = M\frac{(1 - E_F)F_R}{E_F}$$
$$W = W_0 + \frac{W_F + W_C}{2}$$
$$LFI = \frac{V + W}{2M + \frac{W_F - W_V}{2}}$$
$$X = \left(\frac{L}{L_{av}} * \frac{U}{U_{av}}\right)$$
$$MCI_P = 1 - LFI * F(X)$$

Symbol	Definition
M	Mass of a product
F_R	Fraction of mass of a product's feedstock from recycled sources
F_U	Fraction of mass of a product's feedstock from reused sources
V	Mass of virgin feedstock used in a product
C_R	Fraction of mass of a product being collected to go into a recycling process
C_U	Fraction of mass of a product going into component reuse
E_C	Efficiency of the recycling process used for the portion of a product collected for recycling
E_F	Efficiency of the recycling process used to produce recycled feedstock for a product
W	Mass of unrecoverable waste associated with a product
W_0	Mass of unrecoverable waste through a product's material going into landfill, waste to energy and any other type of process where the materials are no longer recoverable
W_C	Mass of unrecoverable waste generated in the process of recycling parts of a product
W_F	Mass of unrecoverable waste generated when producing recycled feedstock for a product
LFI	Linear Flow Index
$F(X)$	Utility factor built as a function of the utility X of a product
X	Utility of a product
L	Actual average lifetime of a product
L_{av}	Actual average lifetime of an industry-average product of the same type
U	Actual average number of functional units achieved during the use phase of a product
U_{av}	Actual average number of functional units achieved during the use phase of an industry-average product of the same type
MCI_P	Material Circularity Indicator of a product
N_i	Normalising factor used to aggregate product-level MCIs using a weighted average approach; the index i refers to a specific product range or department
MCI_C	Material Circularity Indicator of a company

Figure 4. (Ellen Macarthur Foundation, 2016)

4.1.5 *Circular performance index (CPI)*

CPI (Huysman, De Schaepmeester, Ragaert, Dewulf, & Dem Meester, 2017) is a ratio of the actual obtained environmental benefit over the ideal environmental benefit according to quality. The environmental benefit can be calculated by Life Cycle Assessment, for example by using the CEENE method as LCIA.

$$CPI = \frac{actual\ benefit}{ideal\ benefit\ according\ to\ quality}$$

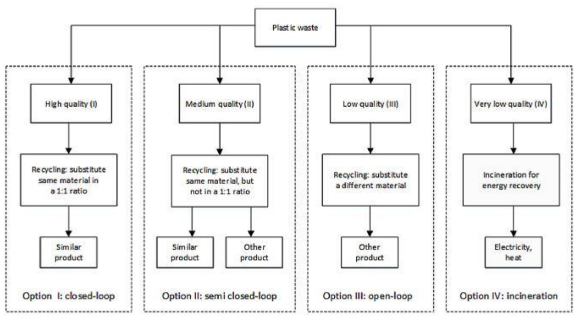

Figure 5. (Franklin-Johnson, Figge, & Canning, 2016)

4.1.6 *Circular economy index (CEI)*

CEI (Di Maio & Rem, 2015) is the ratio of the material value produced by the recycler (market value) by the intrinsic material value entering the recycling facility. To compute the CEI it is necessary to know detailed information of the components and materials contained in each end of life (EOL) product entering the recycling facilities and how they end up in the recycled raw materials. By adjusting for price fluctuations, and therefore it a adjusts for material becoming more expensive due to scarcity, or cheaper because off efficiency gains in recycling technology.

$$CEI = \frac{Material\ value\ recycled\ from\ EOL\ products}{Material\ value\ needed\ for\ producting\ EOL\ products}$$

4.1.7 *Value-based-Resource efficiency (VRE)*

VRE (Di Maio F. , Rem, Baldé, & Polder, 2017) measures resource efficiency and circularity in terms of the market value of stressed resources, assuming that the market value incorporates the elements of scarcity. Applying this definition, circularity is defined as the percentage of the value of stressed resources incorporated in a service or product that is returned after its end-of-life. Y represents the output value, W the weighted price and X the input value.

$$\mathrm{VRE} = \frac{\mathrm{Y}}{\sum_{\mathrm{i}} \mathrm{W_i X_i}}$$

4.1.8 *Ecologic-cost value ratio (EVR)*

EVR (Scheepens, Vogtländer, & Brezet, 2016) is used to analyze potential negative environmental effects on business initiatives on a system level on a three-dimensional approach: companies cost, eco-cost and consumer value. EVR is composed of a ratio of Eco costs, which are the projected monetary impact a product or has on the environment, and the value ratio, which is the projected customer value a good or service has in monetary terms

$$\mathrm{EVR} = \frac{\text{Eco cost}}{\text{Value Ratio}}$$

4.1.9 *Circularity indicator (CIRC)*

CIRC (Pauliuk, Nakamurab, Nakajimac, & Kondob, 2017) is a relative measure of the cumulative mass of a resource present in a system over a certain time interval in terms of an ideal reference case, where the resource remains in functional applications throughout the entire accounting period. Furthermore, data is collected on expected advances in recycling technology, to increase accuracy of measuring the real recycling rate.

$\mathrm{X_u}$ = mass of resource

w = purity, quality and recoverability

t = time

$$\mathrm{w} = \begin{cases} 1, \text{use phase} \\ 0, \text{losses} \end{cases}$$

$$\mathrm{Circ(T)} = \frac{1}{\mathrm{T} - \mathrm{t_0}} * \int_{\mathrm{t0}}^{\mathrm{T}} (\mathrm{X_U(t), w})\mathrm{dt}$$

4.2 Metric evaluation with companies

This chapter consist of an evaluation on how companies found their metrics to perform and be applicable to their business models. The respondents indicated that following metrics are in use within their organization: CIRC, EDIM, RC, EVR, MCI, CPI, Longevity, and VRE. Other metrics were not known or used by the participating companies.

Company	*Metric*	*Function*	*Material*	*Component*	*Product*	*Energy*	*Scope*
A							
	Longevity						1
	CPI						0,1
	CIRC						1
	EDIM						0
B							
	Longevity			X	X		1
	EDIM			X			1
C							
	RR-EOL		X				2
	VRE		X			X	1
D							
	MCI		X		X	X	0,1,2
	CIRC		X			X	2
	EVR		X			X	1,2
E							
	RC		X	X			1
F	Longevity			X			0,1
	EDIM		X	X			0,1
G							
	Longevity			X			1
H							
	MCI		X	X	X		1,2
	CIRC		X				2
I							
	MCI		X	X		X	0,1,2
	CIRC		X			X	2
	EVR		X		X		2

Table 2. Unit of analysis and scope

In the following table the companies were required to rate the metrics they use according to the SMART criteria.

Company	*Metric*	*Specific*	*Measurable*	*Achievable*	*Relevant*	*Timebound*
A	Longevity					
	CPI					
	CIRC					
	EDIM					
B						
	Longevity	7	5	4	4	5
	CPI	3	2	4	7	5
C						
	RE-EOL	7	5	4	4	5
	VRE	7	6	6	7	7
D						
	MCI	4	4	6	5	5
	CIRC	5	6	7	7	7
	EVR	6	6	6	6	7
E						
	RC	7	5	5	4	4
F	Longevity	6	5	7	7	7
	EDIM	7	7	7	7	7
G						
	Longevity	5	4	5	6	5
H						
	MCI	5	4	5	6	5
	CIRC	3	4	4	7	6
I						
	MCI	6	4	5	5	6
	CIRC	3	6	5	7	5
	EVR	5	3	6	6	5

Table 3. Smart evaluation

4.2.1 *Respondents*

The respondent's companies were categorized according to size, revenue, industry, market and visibility of environmental impact. In order to categorize companies by size and revenue, the recommended definition of the European commission has been used (Commission, 2003). In terms of market, respondents were asked whether they operate in B2B or B2C market. The visibility of environmental impact refers to the client's awareness of the impact a product or service has on the ecological- or social environment; to classify the companies, the respondent has been asked to indicate whether the effort a company has to afford to promote a circular business model to the customer base is perceived as low, medium or high. Two factors were hypothesized to have an impact on it: the company's size and its closeness to the end consumer.

Company	Revenue	Size	Industry	Market	Visibility of impact
A	Medium	Medium	Man. of Furniture	B2B	Medium
B	Large	Large	Man. doors & windows	B2B	Low
C	Medium	Large	Disp. Dishes	B2B	High
D	Large	Large	Chemistry	B2B	Medium
E	Very small	Very small	Construction	B2C&B2B	Low
F	Small	Small	Engineering	B2B	Low
G	Small	Small	Construction	B2B	Medium
H	Large	Large	Chemistry	B2B&B2C	High
I	Large	Large	Automotive	B2B	medium

Table 4. Respondent description

After conducting the interviews, following factors contributing to the use and performance of circularity metric used by the included organizations: geographic location of measurement; ownership dispersion of produced good; volume of produced good; quantity of material bill; quantity of suppliers; and visibility of environmental impact.

The findings consist of data gathered from nine respondents working in organizations differing in size, revenue, customer base and industry. The respondent's data provided an indication that scope and unit of measurement a company measures may differ dependent on the aforementioned differences.

Company A is a manufacturer of Furniture based in the Netherlands. Design, assembly and manufacturing is done inhouse. It actively engages in executing circular business models upwards as well as downwards its´ supply chain. The respondent indicated that while it is pursuing to increase the proportion of recycled materials used in production, it engages in refurbishment of used furniture. This is done by offering a buyback program, where owners of the company´s furniture can sell the furniture at a premium.

Company B is a manufacturer of windows and doors based in Poland. In 2017 the manufacturer started a pilot project, where it has partnered with construction companies providing construction services to other businesses. The respondent indicated that by doing so they were able to enter the market of servicing and at the same time create a data stream in order to measure the behavior of their products under real life conditions.

Company C is a manufacturer of disposable dishes based in Poland. With the current EU directive, to phase out disposable plastic dishes, the company the company introduced dishes made out of aluminum to their portfolio. Aluminum, was said, offers a wide range of benefits compared to other materials being used to produce disposable dishes, ecologically as well as economically.

Company D is a manufacturer of industrial chemistry based in Germany. The pursue to act environmentally responsible is part of its mission statement. It has extensive measures to ensure its business models being and becoming more circular and environmentally friendly. A large part of such measures lies in imposing own set restrictions and regulations with regard to the production of its suppliers. Another major part is the dealings with waste management.

Company E produces kinetic machinery for manufacturing companies. Design, assembly, and servicing of these machines are made inhouse, where engineers and assembly workers are working geographically closely together. The companies´ client base is loyal and consist up to 3/5 of recurring customers, where sold machinery usually does not change ownership. Information management has migrated towards using an ERP system, where customer-, staff- and client-data is preserved and managed. In order to increase efficiency and service times, the company introduced a novel plug & click method, where architecture of machinery is not screwed and melted together anymore; stability is provided by weight and product design. By cooperating closely with assembly workers, the engineers were able to introduce a novel, unified construction method and accelerate the learning curve. Outgoing machinery is monitored by assigning unique RFID codes to each and its corresponding data file. The respondent indicated that "the combination of in-house assembly, product design, ERP-system and the loyal customer base is key to being able to use the longevity and EDIM metric effectively. Metrics measuring the circularity downwards the supply chain were not considered as being viable to the company. The respondent indicated that the main reasons were the lack of monetary incentives by customers, lack of resources to devote for data collection and that the supply chain does not possess sufficient infrastructure to measure and share data on circularity. The respondent indicated that, provided a non-complex, easy to access and widely accepted register, like a resource passport exists, the company would consider applying metrics measuring scope 1 and 2.

Company F since founding the construction company, the company is engaged in utilizing construction waste after finishing projects. Since 2018 it decided to measure the recycling rate of construction waste in context to attract new, environmentally aware customers. After a construction project is finished, the client is provided with documents containing data on the proportion of recycled waste. To realize the offering, the company was required to digitize bookkeeping and customer correspondence. It partnered with local public recycling landfills to be able to measure accurately the proportion of recycled material.

Company G is a construction company based in Germany. By forming long term relationships with local maintenance companies, the company was able to standardize construction and maintenance processes. Maintenance costs were cut by approximately 15%, and the projects were able to be executed 10% faster compared to when working with new companies. It actively measures longevity and EDIM. Project management is mainly done by company G, where the project manager assigns dates and workload among partnering companies, and frequent meetings to discuss progress.

Company H is a manufacturer of paint based in Germany. In recent analysis it found that its customers dispose on average 20% of purchased paint. Especially customers disposing paint into their sinks or trash poses issues for the environment. By forming a partnership with a waste management company, it started a pilot project to collect unused paint and containers of construction companies and business consumers.

Company I is a manufacturer of oils and filters based in Germany. Although being present in its mission statement, it has had difficulties in enforcing environmental responsibility. This held especially true, when enforcing its´ own-set regulations and restrictions downwards its supply chain in China. Furthermore, it engages in managing waste upwards its supply chain by outsourcing its waste management.

4.2.2 Core factors affecting measurement performance

After conducting the interviews, following factors contributing to the use and performance of circularity metric used by the included organizations: Geographic location of measurement;

ownership dispersion of produced good; volume of produced good; quantity of material bill; quantity of suppliers; and visibility of environmental impact.

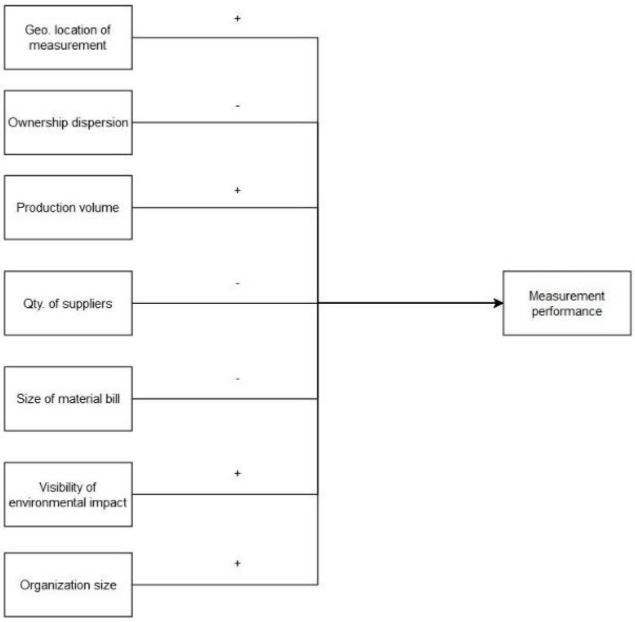

Figure 6. Theoretical model

4.2.3 Geographic location

The geographic location of measurement represents the location, from where data is collected or evaluated. It is hypothesized that the exchange of data between companies at farther distances may be complicated by differences in communication methods, culture, physical distance or regulation.

Company F measures their unit of analysis locally and privately, either inhouse or at the site of the customer only. The Longevity metric and EDIM were reported to perform well for company F, the closer the customer of the bought machinery was located, as servicing could be done more frequently. This was the case, as servicing products at larger distance was more resource intensive. It has been reported that the data gathered is traceable, specific, and comparable over periods of time. Similar findings were reported by company A, where furniture was bought more frequently by company, who were located nationally than internationally; by equipping each piece of furniture with its unique code, this enables company A to increase traceability and reliability of measurements.

Company B, E, G and I rely on third party organizations, where circularity performance is measured. Data gathered from third parties, like servicing- or waste utilizing companies, or public institutions, like public landfills, were consistently reported to provide reliable and rich data whenever they were located locally or nationally. Company I reported that, in recent years, they were outsourcing steel manufacturing to companies from China. The respondent emphasized that: “Chinese companies were commonly underbidding their competitors during tendering while agreeing to quality and environmental requirements. After winning the tendering process, Chinese manufacturers tended to either underperform or provided companies I with fraudulent data on the origin of manufactured resources”. Therefore, measuring CPI could only be measured at a national- and European level reliably.

Company D and I were able to use the CIRC metric reliably by cooperating with local waste management companies, which was reported to be highly relevant, as CIRC includes development of future recycling technology performance into decision making. Both respondents claimed that research on the performance of future recycling technology was possible to perform inhouse. However, it was not viable, as it´s resource intensive and waste utilizing companies were able to provide more reliable data due them being specialized in recycling technology. In contrast, company D reported no significant issues, when measuring nationally or internationally. This may be explained by the fact that company D is a member of a corporate alliance, cross-validating, and licensing environmental performance of suppliers and therefore is able to access larger data-pools and cross-verify them. EVR could be measured, as the company has access to reliable data on the environmental impact of its resources.

When measuring circularity performance at farther distances, company I reported that it has had major difficulties in the past to enforce regulations and measure them. When tendering steel manufacturing to producers in China, it was reported that commonly Chinese companies were undercutting competition in pricing, while agreeing to preset regulations on circular and environmental policy. After visiting cites, frequent violations were found. Furthermore, communication of data was reported to be less frequent and the data less reliable than from national suppliers. Future tendering should include transaction and administrative costs, like for plant visits. Companies B, E and G relied on third parties providing data nationally, where companies E and G limited themselves to regional third parties. Companies E and G, being very small and small companies respectively, claimed that their relatively small size and missing infrastructure would disqualify corporations at farther distances.

4.2.4 Dispersion of ownership

The Dispersion of ownership describes the movement and location of a sold product. Location wise ownership is dispersed, if a product is distributed across large populations internationally or intercontinentally, like consumer goods or commodities. Ownership dispersion is further impacted by ownership changes after-sale in form of reselling. While concentrated ownership would be represented by products, which do not move after sale and are distributed among small populations nationally, like real estate or heavy machinery. It is hypothesized that high movement of goods at far distances increases the difficulty of tracking a product, and hence extracting data on it after sale.

The Dispersion of ownership of the products of companies I,H,D and C was reported to be very high. All of the companies reported that measurement of circularity upwards their supply chain was difficult as their products are difficult to track and control after sale. Company C and H are aiming to track the performance of their products upwards their supply chain, by incentivizing the return of used products. By using aluminum, company C uses a material, which landfills pay premiums on their proper disposal. Respondent C claimed that “there is no issue in releasing sheeps over the course of the day, as long as one is able to collect them by evening”. By working with landfills, company C is able to measure RC-EOL of aluminum products. While company H is incentivizing its customers to return unused packages and paint in exchange for a voucher. However, both respondents claim that the data is not reliable and hence cannot function as viable input for metrics yet, as traceability of specific units is not possible at this time. The products of companies A were claimed to have medium ownership dispersion. However, furniture has a significantly longer product life cycle, which increases monitoring efforts. By offering a buyback program and the ability to track the items via RFID codes, Company A was able to mitigate the issue of traceability and recollection. Even though “furniture has often more than one life” as it is repurposed and resold frequently, as respondent A said, company A is still able to measure many items specifically and consistently. At the other hand, company E, F, G have a low dispersion of ownership, and reported consistently that measurements upwards the value chain do not pose many difficulties. Company F has reoccurring customers and its products are not commonly resold, leading to ownership being concentrated. By equipping the items with RFID codes company F is able to measure the longevity and EDIM metric reliably and consequently while servicing, the same counts for company G.

4.2.5 *Production volume*

Production volume refers to the scale of output of a companies end-product. Large scale products may be described as consumer goods or commodities, while low scale products are products like real estate or heavy machinery. It is hypothesized that infrastructure to measure data across supply chains requires high fix costs and commitment, which could be mitigated by economies of scale. Therefore, bearing infrastructure costs at large scale facilities may be more viable than at low scale facilities.

Companies B, D, H and I have high production volumes of their products and D, H and I are able to measure the circularity downwards their supply chain effectively, where company D measures circularity up till 4th degree supplier, H and I till 2nd. It was reported that by being able to purchase large quantities from suppliers, companies are able to increase their bargaining power and enforce policies on suppliers. Respondent A reported that its` company has aspirations to measure circularity downwards their value chain. However, raw materials are commonly purchased by procurement pooling and due to Company A´s low purchasing volumes, suppliers are not willing to measure and provide data on the circularity of their production. Especially reliable data on the composure of metals is difficult to acquire, as it was reported that resources are not available to check composure of metals. Companies E, and F have low volumes of production and claimed that their bargaining power was to low to incentivize suppliers to provide data on circularity. Company G did not intend to measure circularity downwards its value chain.

4.2.6 *Size of material bill*

Size of material bill represents the purchased quantity of differing components a company has. Companies with large sizes of material bill may be companies producing high complex machinery with high amounts of separate components, while companies with low sizes of material bill may be companies producing low complex goods like commodities or furniture. It is hypothesized that a large size of material bill increases the count of components required to measure and hence the complexity of measurement itself.

Respondents of companies D,H and I reported that by using their environmental- and circular regulations, they were able to decentralize and reduce complexity in measuring the circularity downwards its supply chain. This was necessary for supplies which provide goods at high quantities and are of low monetary value. By doing so, administration costs were able to be kept relatively low. Suppliers were asked and incentivized to enforce regulations further down the supply chain, which ideally may result in the development of measurement capabilities across the entire supply chain. At the same time company A intends to measure circularity downwards their supply chain by choosing suppliers, who offer circular business models. However, not all suppliers offer circular business models, and materials like wood, which is purchased by using purchasing pooling and is responsible for most of the material bill, is not measured with regards to its circularity effectively. Furthermore, the strategy to choose suppliers with circular business models when tendering was reported to not deliver comparable performance measures, as suppliers' methodology of assessing circularity may differ extensively. Respondent A indicated that suppliers using the recycling rate for assessing circularity may be misleading, as it disregards the proportion of hazardous materials in its´ calculation. Respondent C indicated that it´s material bill was low in volume and hence in complexity as it purchases large volumes of few materials. In case of aluminum dishes, the core resource is aluminum. Measuring VRE downwards it´s supply chain yielded constant and reliable results. This has been achieved, as aluminum was supplied by three international suppliers, which could be met personally regularly. Respondent C indicated that assessing circularity of its core resource downwards its supply chain may be achieved easily as administration costs are low. Companies E, F and G did not assess circularity downwards its´ supply chain. While F did not intend to measure downwards at all, respondent E and G reported that projects vary extensively and so do its´ material bill. The administration effort is the main reason according to all respondents, why a company may not want to take measures to assess circularity downwards their supply chain.

4.2.7 *Quantity of suppliers*

Quantity of suppliers refers to the supplier count a company has. Companies with high supplier counts may be complex machinery producers like automotive companies, while companies with low supplier counts could be producers of commodities. It is hypothesized that high supplier counts increase the complexity of data collection as it requires companies to invest more in communication channels and infrastructure.

Companies D, H and I have more than ten thousand suppliers worldwide each. In order to be able to monitor the performance of suppliers, companies D and H joined procurement institutions, which audit and develop suppliers to adapt circular business models and to enable to share data upwards and downwards the supply chain. By cooperating with private corporations, company D is able to assess up to 70% of its´ suppliers circular performance and up till the 3rd level supplier. By joining procurement institutions, MCI and EVR can be measured reliably. Company I is not a part of any network and by assessing circularity on its own. It reported to measure about 40% of its suppliers with regards to circularity by using MCI and EVR. Companies A, B, C, E, F and G have between hundred and thousand suppliers. Companies E, F and G reported that the number of suppliers they are working with is not viable to be able to measure circularity, as methodology of suppliers measuring circularity differs and administrative costs are to high. Company A reported that they had been using RC as a performance measurement of suppliers. RC was suspended, as methodology on measuring RC differed among suppliers and therefore didn´t reflect accurate data. Respondent B reported that due to its low number of suppliers and high expertise in the resources they transform, they can measure VRE, which was considered superior to RC, as in contrast to RC, VRE includes market prices as a scarcity indicator. This adds an additional qualitative measure the metric.

4.2.8 *Visibility of environmental impact*

Visibility of environmental impact has been commonly reported to be impactful on decision making with regard to whether to measure circularity. Respondents F and G, who reported to perceive low or medium attention with regard to e-impact, explicitly claimed that the intention to assess circularity within their value-chain is primarily motivated by expected efficiency gains, and they did not perceive the need- or will- to increase efforts in measuring circularity due to environmental reasons. While Respondents A, C, D, H and I have claimed, that due to an increase of demand and public attention environmentally friendly products have witnessed in the last decades, they were motivated to establish circular business models and are willing to continue. Respondent E stated that even though demand for recycling is still low at the client's side, he perceived an influx of customers who are willing to pay premiums for services of reliable waste management.

4.3 Metric evaluation

This chapter provides a discussion on the metrics´ attributes; evaluates their strengths and weaknesses and discusses conditions under which case a certain metric may be preferrable. Furthermore, it serves as an answer to RQ 1.

Participating companies, who were able internalize the manufacturing and servicing part of a products value chain, commonly used EDIM and Longevity metric, which has been true for companies A, F and G. The internalization of these parts of the value chain may have allowed the companies to develop an imperative understanding of their products and services, and therefore the expertise required to measure Longevity and EDIM was not necessary to be developed prior to using the metrics. This is especially reflected by company E´s scores on the SMART scale, where both metrics received scores no less than 5 (see table 3). If reliable traceability and the required data collection infrastructure were available, these metrics proved to be reliable and effective. Companies B and G made use of external servicing companies to be able to acquire the data. Company B, which is solely responsible for the manufacturing of windows and doors, performed the data evaluation themselves, whereas company G consulted with servicing companies. Out of the respondent's group, Longevity, EDIM were the only metrics, which are in use primary for economic reasons, which may indicate that businesses and organizations may be encouraged by profits to engage in using them. Another aspect is the fact that companies of large till small size are using EDIM or Longevity, and it performs best at the small company F (see table 3). Companies, where products or services were reported not to be traceable did not use neither longevity nor EDIM to measure circularity. Another aspect is that companies using EDIM or Longevity were doing it independently of whether their customers communicated a demand for environmentally friendly action.

Large sized companies, who reported to have more than ten thousand suppliers were actively measuring circularity downwards their supply chain. However, Company D, which is a member of a data sharing alliance, stands out, when measuring circularity downwards its supply chain. The results are reflected as well by the scores at the SMART scale (see table 3), where company D consistently gave scores ranging 4-6 across specificity and measurability. Measuring circularity downwards the supply chain involves high fixed costs and supply chain integration, which to many companies still poses a challenge, making metrics like MCI, CIRC, EVR or CPI difficult to apply on one own; especially the integration of intercontinental supply chains posed large difficulties. This was observed on the scores of the SMART scale, where company I gave scope 1 and 2 metrics scores of as low as 3 in terms of specificity and measurability. Besides entering a data sharing alliance, making use of waste management companies has shown to lead to reliable results, too. VRE, even though only being used by one respondent, has shown to offer companies the possibility to measure their resource efficiency by composing the ratio of monetary resource outputs and monetary resource inputs.

5. DISCUSSION AND CONCLUSION

It is widely agreed that up until now there is no standardized or well-established metric to measure circularity. Due to this fact, interviewed companies, especially those who were measuring circularity downwards their supply chain, where supply chains exist on a global level, have endured significant fixed costs when establishing their measurement infrastructures; at the same time, companies seem not to utilize existing synergies between own-established measurement infrastructure and are, therefore, posed to carry fixed costs alone. First initiatives to form Alliances between companies with regard to sharing data on supplies and suppliers were observed. Very small to medium sized companies appeared to have similar capabilities with regard to collecting data on circularity, as most of those interviewed companies were collecting data only with their immediate environment. This indicates that the difficulty of measuring circularity increases non-linearly but exponentially when increasing scope of measurement. Especially small or medium sized companies, which engaged in servicing their products were able to utilize the longevity or EDIM metric consistently, reliably, and over longer periods of time. Both, high degree of understanding its product and the low complexity of data collection seem to allow companies who engage in product service systems to measure circularity with a relatively low degree of effort. Interviewed companies of large size, which measured circularity downwards its supply chain on their own, could do that to a smaler extent and less reliably. Only one company, being classified as large, has been able to measure circularity downwards its supply to a satisfying degree. Leveraging the measurement infrastructure of manufacturing companies, collecting, and comparing data on similar suppliers or supplies seemed to impact the ability to measure circularity at scope one and two positively. Agreeing on similar standards and leveraging established infrastructures to collect data allowed the company tap into larger data pools, reduce fixed costs due to economies of scale and make data comparable. The imperative way of measurement seemed to be by outsourcing measurement to a third party being specialized in recycling or waste management, like landfills or waste management companies as metrics used in combination with outsourcing measurement not only provided companies with quality and reliable data, but it has also been significantly less expensive as well. Product service systems and outsourcing or sharing the fixed costs of measuring circularity downwards the supply chain appeared to be promising and viable to promote adoption. A proposed solution to utilize established data collection infrastructures, use economies of scale and make data comparable is the resource passport by (Damen, 2012) . By reducing complexity and costs, small or medium sized companies could be encouraged to increase their efforts in measuring circularity and adapting their behavior to reduce their environmental footprint.

5.1.1 Research question 1.1

To answer RQ. 1.1 and show whether there exists discrepancy between the private and academic field on how to measure the circularity of value chains effectively more research needs to be done. However, what this research indicates is that participating companies, which perform circularity measurements downwards their supply chain and which have other business models than waste utilization and are not operating in data sharing alliances, have difficulties to retrieve data from suppliers necessary for metrics measuring scope 1 and 2, regardless of the size of the company, its revenue or industry. This indicates that metrics aiming to measure circularity downwards companies value chains provided by academia experience diminishing returns with increasing scope of measurement using the companies´ own-established infrastructure regarding effectiveness of measurement. To conclude, the discrepancy between the academic and private field appears to increase with increasing scope of measurement.

5.1.2 Research question 1.1.2

An explanation to why there appears to be discrepancies between the academic- and private field with regard to effectiveness of measuring the circularity of value chains is the potential missing understanding of the non-linear increase of difficulty in data collection across supply chains and the companies limited resources to do so. Furthermore, management sciences may still lack practical methods on how to execute data collecting methods within businesses and their supply chains. The provided scope 1 and 2 metrics do not seem to cope for the infrastructural boundaries of the private companies, making them less viable to use with increasing scope of measurement.

5.2 Limitations and further research

This research consists of nine interviews with interviewees representing companies differing in size, industry, and revenue. Furthermore, the interviewees are occupying differing positions. Due to the small and differing sample, the stated results are not statistically significant. The reader should account for the fact that the interviewer's ability to control for the understanding of metrics of the interviewees was limited, and therefore the reasoning on why companies decided to use- or not to use- a metric may differ and have an impact on the comparativeness of the results. Another aspect to point out is that even though the interviewer communicated to the interviewees that the interview-data would be anonymized, still, due to the interview being held via video conference or call, the interview method may have been obtrusive. However, this research provides qualitative data on companies' effectiveness and challenges, when assessing the circularity of their business models and points out that, due to limitations of companies' resources, differing nature of goods and services, companies' environmental engagement and international information asymmetries there may be a discrepancy between the scientific- and business community. The results may as well serve as practical management advise in terms of decision-making, when deciding on the applicability of a metric to a certain circular business model.

Further research may include more detailed and empirical research on the impact on measurement performance each factor has. Additionally, further research may include research on business practice in integrating circularity metrics in supply chains.

6. ACKNOLEDGEMENTS

First and foremost, I would like to thank my supervisor, G.C. Capelleveen, who provided constant educational and personal guidance during extraordinary times. He has proven to be a compassionate, wise and -most importantly- patient supervisor. Further acknowledgements go to the staff of the University of Twente for their efforts in reengineering their study model, so that disruption of students' life could be minimized.

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