Quantifying The Circularity of Regional Industrial Waste Across Multi-Channel Enterprises

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Abstract

Circular Economy is a theoretical concept that is widely discussed in recent literature as a way to achieve increased sustainability. However, published literature focuses on how to increase circularity without analysing the status quo of circularity, which necessitates answering the question of how to measure the effectiveness of any actions implemented to advance Circular Economy. Currently, there is no agreed methodology in literature on measuring the existing circularity. Therefore, this article proposes an analytical way to measure and map a regional waste economy's circularity. The framework can be applied at a granularity of an individual materials level as well as overall at a regional level, and can quantify with a potential to improve towards a more circular economy in value as well as in volume.

Data mining, conditioning, and, mathematical analysis was conducted across a number of public and private databases such as ORBIS and The Environment Agency. The proposed framework was tested taking a case of a region in the North East of England with 35,116 active companies. The methodology was validated on a different data set from another region. The results show that the methodology is able to measure a regional circularity overall as well as at an individual material level. The outcome of this research would be useful for policy makers as well as manufacturing organisations, and waste management companies as benchmarking allows a comparison between effectiveness of regional environmental regulations with their influence on driving sustainability and Circular Economy.

Keywords: Circular Economy, Analytical Framework, Waste Management, Environment, Environmental Sustainability, Waste Input-Output Analysis

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1. Introduction

A growing population worldwide and an increasingly strong middle-class enhance the global demand for natural resources, products and services (Lieder and Rashid, 2016; Allwood et al. 2011). This development presents a challenge for the environment and the economy in terms of balancing to satisfy the demand through expanding industrial production and new technologies without compromising living opportunities for future generations (European Commission 1994; European Commission 2006; European Commission 2008). In particular, increased competition for limited natural resources outlines the deficiency of the current Linear Economy of "take-make-use-dispose" (Elia et al. 2017; Ellen MacArthur Foundation 2015; Gebler et al. 2014; Environmental Audit Committee 2014). The urgency of an international change in priorities towards more sustainability in economic production becomes obvious when observing the increasing risk of catastrophic environmental events. Accordingly, this dilemma has recently received growing attention from governments, NGOs and companies alike (Kristensen et al. 2016; Andrews 2015; Zhao et al. 2017; European Commission 2016). To save the environment and its limited resources for future growth and prosperity the international economy needs to change in its view towards sustainability. For a sustainable growth, the goals for the current and future economies should be to optimise the usage of limited natural resources, decrease emissions, reduce material loss, increase the usage of renewable and recyclable resources, prevent down-cycling of material quality, and increase value preservation of materials and products (Ellen MacArthur Foundation 2015b; Despeisse et al. 2017).

The challenge, however, lies in the goals' complexity. From re-orientation of consumer thinking to setting up a suitable political environment, increasing the economic sustainability involves every stakeholder and all of their divergent aims (Sauvé et al. 2016; Brandenburg and Rebs, 2015). Accordingly, a holistic approach towards a more sustainable production, consumption and waste management is needed. To ensure progress, the responsibility lies with producers, sellers and consumers to minimise the direct and indirect emissions, and waste (Liao et al. 2015; Lopes de Sousa Jabbour et al. 2018). Development towards Circular Economy could be one of the pathways for achieving a sustainable growth. One of the first steps towards making stakeholders realising the need for change would be to measure the current level of circularity so as to improve the precision of future actions. Literature agrees that change is necessary, however, it has not currently been determined by research, whether existing frameworks and methodologies can be successfully used to measure circularity. Additionally, being unable to measure the current level of circularity the environmental effectiveness of any changes proposed is unclear (Elia et al. 2017). Whether actions that supposed to improve economic activities are successful or not can only be determined and proven by comparing to the status quo. Therefore, a framework is needed to provide such a measurement.

A first step towards more circularity could be to increase companies' understanding of the benefits through quantifying waste flows and introducing a comprehensible methodology to measure circularity (Salemdeeb et al. 2016). Accordingly, it needs to be determined if the recent findings in the literature dealing with benefits of Circular Economy for the industries could be transferred for contributing towards increasing the circularity of a given region. Therefore, the main research question within this context is: ***How can the circularity of a region be measured in general and on an individual material level?***

In order to address this research question, we proposed a framework for measuring and mapping regional waste economy with the objective to analyse and quantify the flow of individual materials in the economy. We collected data from a large number of databases for example, ORBIS, The Environment Agency and the national Waste Input-Output Table to validate the proposed framework. The collected data required rigorous cleaning and conditioning before it could be used for the analysis. We selected the North East region of England (Durham and Darlington) as our field of study to implement the proposed framework and the region of Newcastle upon Tyne to compare the results for validation of our framework. There are around 35,116 active companies in the region of Durham and Darlington and about 67,476 active companies in the Newcastle area, all of which are divided in several industry sectors based on their capabilities. We were able to successfully map the flow of individual materials across the industry sectors and were also able to measure the circularity of the flow. The results were highly encouraging as it confirmed that the proposed framework is able to measure an economy's circularity that too at an individual material level. The outcome of this research would be highly useful for policy makers, manufacturing organizations, and waste management companies.

This paper is structured as follows: next section establishes the theoretical background of this work. Section 3 presents the details of the research methodology. Section 4 presents the results and discussion and Section 5 summarises the overall findings. Section 6 presents the conclusions, limitations and potential for further research.

2. Literature Review

Although literature is divided about a clear definition of Circular Economy, agreement is reached on it being the opposite of the current Linear Economy of unidirectional material flows based on the principle of "taking-making-using-disposing" (Elia et al. 2017; Ellen MacArthur Foundation 2015; Kristensen et al. 2016; Sauvé et al. 2016). For the purpose of this research, only the EU definition of Circular Economy is taken into further consideration which states, "*In a circular economy the value of products and materials is maintained for as long as possible. Waste and resource use are minimised, and when a product reaches the end of its life, it is used again to create further value*". This definition associates Circular Economy with different aspects of a product's lifecycle; material input, eco-design, production, consumption and waste recycling (EEA 2016; Ellen MacArthur Foundation 2015b; Rowe et al. 2017). It has its origins in various other disciplines and frameworks such as the product life and the substitution of services for products (Stahel 1997), the cradle-to-cradle approach, (McDonough et al. 2003) and the Industrial Ecology (Graedel and Allenby 2003).

Despite the concept of Circular Economy receiving increasing international attention by governments, companies and researchers alike, relevant literature is scarce (Kristensen et al. 2016; European Commission 2016). Given the importance of economies developing towards circularity to ensure long-term growths in the context of limited virgin resources, it is necessary to establish a clear framework and measurement to improve sustainability within a system. This area is surprisingly still widely neglected by research.

One of the main questions in relation to this research is whether existing methodologies can appropriately measure the circularity of an economy or a region. Literature has proposed various calculations, indicators and frameworks to determine environmental impacts. Some favour single or multiple indicator approaches basing the assessment on the amount of resources used (Elia, et al. 2017) such as the water footprint, which analyses the total amount of water consumed or polluted throughout a products supply chain and is measured by the international standard ISO 14046 (Hoekstra, Hung, 2002; International Organization for Standardization, 2014). However, as the names of these calculations indicate, only one or a limited amount of impacts are taken into account not allowing a holistic picture of the total environmental impact of a company, process or product. Other researchers consider the household-recycling-rate to quantify circularity within an economy. In this indicator, only the quantity of private households' contributions towards a Circular Economy is counted. Such approach does not take industrial waste into consideration, which is accountable for the majority of waste within an economy (Environmental Audit Committee, 2014). Accordingly, their indicator approaches are unable to include the complexity of Circular Economy in their analysis.

Although the literature uses various models to match waste to potential input in a different company, the most consistently applied framework is the Material Flow Analysis (Hendrickson, et al. 1998; Salemdeeb, et al. 2016). The Material Flow Analysis can be carried out to measure environmental impacts through the flow of material within a system (Brunner, Rechberger, 2004). However, just like the aforementioned models, it only focuses on a limited number of indicators. Simultaneously, the model is a rather simplistic linear mathematical approach, which insufficiently relates to industrial reality.

Zhao et al. (2017) find that eco-industrial parks are a credible way to enhance the emerging of a recycling economy using the Grey-Delphi method to evaluate decision making. Primary data from Chinese eco-industrial parks is used to prove the credibility and success of Circular Economy in a real environment. Despite the method of a hybrid multi-criteria decision making approach being a reasonably comprehensive choice, the lack of explanation as to how consensus is achieved questions the reliability of the results. Additionally, Zhao et al. use Chinese eco-industrial parks as their test areas. These parks are specifically constructed environments to ensure the success of Circular Economy within their borders. These parks are designed to make Circular Economy work. Accordingly, it is questionable if the results can be transferred to other regions, in which the economic structures result from industrial growths and structural change over decades.

The UK Waste and Resource Action Programme conducted a study and a follow-up to estimate waste in the food industry based on secondary data sources and basic mathematical analysis (Waste and Resource Action Programme 2013; Waste and Resource Action Programme 2016). However, the focus was only on food waste and the mathematical analysis conducted was very simplistic and did not reflect the complexity of the supply chains and their numerous influential external impacts.

Salemdeeb et al. (2016) investigated the shortage of analysis of the relation between economic pursuits and the generation of waste with the intent to outline potential to increase collaboration, and consequently develop towards a more circular economy. They use secondary data consisting of various industrial sectors, different waste types and the amount of waste produced. Within the year 2010 waste was quantified throughout a supply chain by using a mathematical structure similar to the principles of the Input-Output-Table (Salemdeeb et al. 2016; Miller and Blair 2009).

Based on the fact that there is no common approach to measure and practically investigate Circular Economy agreed in the literature, different methodologies are used in the few research studies that present data. Furthermore, Elia et al. (2017) argue, that unless research agrees on a universal method of measuring Circular Economy no comprehensible and justifiable changes can be made in legislation and company regulation. Although this is a recurring theme in recent literature, research acknowledges challenges in how to quantify environmental data, how to secure data availability and how to include multiple dimensions of influences into consideration. Despite these arguments being very compelling, none of those articles offers a practical solution on how to measure circularity within an economy or a region (Elia et al. 2017; Wyaokińska 2016; Pomponi and Moncaster 2017; Geissdoerfer et al. 2017).

Generally, research agrees that the entire concept of Circular Economy lacks exploration and those that exist lack quantitative data (Kristensen et al. 2016; Sauvé et al. 2016; Guo et al. 2017; Geng et al. 2012; Bilitewski 2012). Kristensen et al. (2016), for instance argue, that "*this increasingly influential approach remains unexplored in terms of its potential*", but they recognise that changing this would only be possible by reaching a broader understanding of the importance of stakeholders involved and their need of increased collaboration and partnership. A questionnaire survey on Circular Economy was conducted in Western China (Guo et al. 2017). The summarised results showed that though legislation was involved in implementing Circular Economy, participants were unaware of its meaning. Despite the concept becoming increasingly influential, apparently it lacked public attention. Although the research used very limited data due to the geographical area of the investigation and the political restrictions, it clearly showed that less than 50 percent of participants only knew the concept of Circular Economy, let alone knew key underpinning ideas behind such concepts. Accordingly, a universal framework is needed to educate stakeholders on the concept of circularity (Guo et al. 2017).

Summarising the central findings of the literature investigating Circular Economy, it can be concluded that the concept lacks exploration, especially in a practical context. Articles summarising other research agree on five repetitive themes as mentioned below but do not provide much practical evidence or solutions.

- There is no universal method of measuring Circular Economy available (Elia et al. 2017; Wyaokińska 2016; Pomponi and Moncaster 2017; Geissdoerfer et al. 2017).
- The concept of Circular Economy lacks exploration (Kristensen et al. 2016; Sauvé et al. 2016; Guo et al. 2017; Geng et al. 2012; Bilitewski, 2012; Lopes de Sousa Jabbour et al. 2018).
- The current concept of Linear Economy is unsuitable for long-term success (Andrews, 2015; Franklin-Johnson et al. 2016; Singh and Ordoñez 2016; Wyaokińska 2016; Bilitewski 2012; Geissdoerfer et al. 2017; Jiaoa and Boons, 2017; Lieder and Rashid 2016; Allwood et al. 2011).
- A change in mentality and design of products and processes is needed (Franklin-Johnson et al. 2016; Singh and Ordoñez, 2016; Wyaokińska 2016; Bilitewski 2012; Pomponi, Moncaster, 2017; Ghisellini et al. 2016; Foran et al. 2005; Allwood et al. 2011).
- Top-down and bottom-up support is needed for Circular Economy to succeed (Winans et al. 2017; Jiaoa and Boons 2017; Lieder and Rashid 2016).

The Input-Output-Table as a methodology is very common in investigating waste flows and waste management (Salemdeeb et al. 2016; Jensen et al. 2013; Nakamura et al. 2007; Court et al. 2015; Foran et al. 2005). However, the Input-Output-Table methodology has never been used to investigate and quantify Circular Economy. Analysing the current situation, e.g. where waste comes from (industry, company or geographic region) and what influences its quantity and its type (hazardous or not) is a first step towards evaluating change (Kettinger et al. 1997). This analysis allows a quantified statement about the status quo of individual regions and waste types in connection with their level of circularity. Knowledge about the current degree of circularity enables the identification of areas with need for change as well as an examination of the success through improvement measures. An adaptation of the Input-Output-Table might allow conclusions on what the main driving forces in waste generation are and which sectors are especially problematic to then quantify potential to increase circularity.

It may therefore be advantageous to take literature's analysis further and link Input-Output-Tables to Circular Economy through analysing quantitative data, advancing the aforementioned published conclusions towards a practical example. Simultaneously, this could establish Input-Output-Tables as a methodology to measure circularity within an economy. A link between the waste generation and the economic activity is required in order to encourage the adoption of Circular Economy praxis (Salemdeeb et al. 2016). However, a conclusion towards necessary changes to better measure Circular Economy also needs to be advanced. The practical examples have shown, that if regions are specifically designed to foster Circular Economy, great benefits for companies and the environment can be achieved (Zhao et al. 2017; Guo et al. 2017). It is highly desirable for companies outside these designed areas to replicate the economic advantage Circular Economy provides.

However, it remains to be tested if the level of circularity can at all be measured in a mature-economy or region in which industry is shaped by history and struggles of structural change. Therefore, an investigation combining the frameworks of Circular Economy and Input-Output-Tables will be conducted to better understand general waste generated by companies, especially when focussed on specific types of industries and explicit regions to outline the status quo of circularity in these regions and identify potential for improvement.

3. Research Methodology

This section presents the details of the research methodology adopted for this study (Figure 1).

<<Insert Figure 1 about here >>

The research question was to determine how to measure the circularity of a regional economy in general and at an individual material level. The North East region of England (Durham and Darlington and in comparison Newcastle) was selected as a case example (Figure 2).

<<Insert Figure 2 about here >>

The overall regional economy was mapped to identify the existing links among industry sectors. Data for all active companies in Durham, Darlington and Newcastle were collected from databases and analysed based on their key capability and sector to develop the links among the organisations. This data includes companies' industry sector, size, location, and other similar characteristics. In addition, data to estimate an overall likely structure of trade relationships between the identified companies were collected to analyse the regional Circular Economy status in depth. This research adopted the Waste Input–Output Table (WIO) for its quantitative analysis to outline a holistic picture of circularity within a system (Miller and Blair, 2009; Hendrickson et al. 1998). The WIO analyses the flow of goods, services, and waste across industry sectors (Nakamura and Kondo 2009; Salemdeeb et al. 2016; Liao et al. 2015; Court et al. 2015; OECD 2015). As a result it presents the industry sectors in a matrix where each row and column represents a sector and the value indicates the inter-sectorial trade relationship. For example, selecting an industry in a row, the corresponding values in the columns represent the value of goods sold as output to the different sectors. Similarly, the columns represented the value of input received by the respective sector from other sectors. The WIO allows a better understanding of the interdependence between industrial production and waste generation (Miller and Blair 2009; Salemdeeb et al. 2016; Court et al. 2015; Foran et al. 2005).

The mathematical matrix is the underlying basis for the table visualisation as well as for the more abstract matrix version. If n^I is the number of goods and service sectors analysed and n^{II} is the number of waste treatment sectors, then the number of companies in the investigated economy or region is

$$n = n^I + n^{II} \qquad (2).$$

If N^I is the overall set of goods and service sectors, it has to be defined as N^I: {1, …, n^I}. Similarly, the overall set of waste treatment sectors is N^{II}: {n^I+1, …, n^{II}}. Accordingly, the overall set of sectors in the economy is N: {1, …, n^I+n^{II}}. If now, within the overall system two example sectors i and j are analysed, the following restrictions are in place; $i \in N$ and $j \in N$ and $i \neq j$ (Nakamura, Kondo, 2009; Nakamura, Kondo, 2002; Court, et al. 2015; Liao, et al. 2015; Miller, Blair, 2009; Nakamura, et al. 2007; Jensen, et al. 2013).

For sector j the output is defined as x_j and the input from i to j is defined as X_{ij}, a matrix tying together the sectors i and j. Accordingly, the input matrix between sectors i and j would be:

$$X_{ij} = \begin{pmatrix} X_{1,1} & X_{1,2} & X_{1,3} & X_{1,4} & \cdots & X_{1,n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ X_{n,1} & X_{n,2} & X_{n,3} & X_{n,4} & \cdots & X_{n,n} \end{pmatrix} \qquad (3)$$

where $n = n^I + n^{II}$. This matrix X shows which sector receives input from which other sector within the investigated economy or region. $X_{1,1}$ symbolises the input that sector one receives from itself, while $X_{1,2}$ is the input one sector one receives from sector two (Nakamura, Kondo, 2009; Nakamura, Kondo, 2002; Nakamura, et al. 2007). The sum of all input different sectors are receiving from one sector accordingly has to be the sector's output in goods and services, disregarding the output as waste.

If furthermore, n^w is the number of different waste types, then the overall set of waste types N^w is defined as N^w: $\{1, \ldots, n^w\}$. If now only one type of waste is analysed as k ($k \in N^w$), the generation of waste and its usage as input can be measured. The matrix W^+_{kj} hereby represents the waste generation that is added to the environment (+) of sector j and waste type k by producing goods and services and selling them to other sectors. Generalising, W^+ shows which sector generates which types of waste (Nakamura, Kondo, 2009; Nakamura, Kondo, 2002; Court, et al. 2015).

$$W^+_{kj} = \begin{pmatrix} W^+_{1,1} & W^+_{1,2} & W^+_{1,3} & W^+_{1,4} & \cdots & W^+_{1,n^w} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ W^+_{n^w,1} & W^+_{n^w,2} & W^+_{n^w,3} & W^+_{n^w,4} & \cdots & W^+_{n^w,n^w} \end{pmatrix} \quad (4)$$

Correspondingly, W^- shows which sector is using which type of waste as input. Since any waste used by a sector will not contribute to environmental waste, this matrix is labelled with a negative sign (-) to show that its effect is subtracted from overall waste output. The matrix W^-_{kj} therefore lists the waste used as input of sector j and waste type k (Nakamura, Kondo, 2009; Liao, et al. 2015; Nakamura, et al. 2007).

$$W^-_{kj} = \begin{pmatrix} W^-_{1,1} & W^-_{1,2} & W^-_{1,3} & W^-_{1,4} & \cdots & W^-_{1,n^w} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ W^-_{n^w,1} & W^-_{n^w,2} & W^-_{n^w,3} & W^-_{n^w,4} & \cdots & W^-_{n^w,n^w} \end{pmatrix} \quad (5)$$

In this notation W represents the total amount of waste, being defined as

$$W = W^+ - W^- \quad (6).$$

If $W > 0$, then $W^+ > W^-$ and more waste is generated then used, which probably is the usual case in normal economies. This waste then has to be disposed of. However, from a mathematical perspective $W < 0$ would be possible, meaning that $W^+ < W^-$ and more waste would be used as input than waste is generated (Nakamura, Kondo, 2009; Nakamura, Kondo, 2002; Jensen, et al. 2013). This would correspond to the spurious case where less efficient sustainability practices would be sufficient.

Summarising the aforementioned considerations the overall input per sector can be calculated as following:

$$\mathbf{x_i} = \sum_{\mathbf{j} \in \mathbf{N^I}} \mathbf{X_{ij}} + \sum_{\mathbf{j} \in \mathbf{N^{II}}} \mathbf{X_{ij}} + \mathbf{X_{iF}} \quad (7)$$

with ($i \in N^I$). This means, that the output of one goods sector i is the sum of all output from sector i to other goods sectors j ($j \in N^I$), plus the sum of all output from sector i to waste treatment sectors j (j ∈ N^{II}), plus any external direct demand for output from sector i (Nakamura, Kondo, 2009; Nakamura, Kondo, 2002; Nakamura, et al. 2007).

This basic idea is similarly applied to analyse the output of any waste treatment sector m, in relation to other sectors j within the restriction of m (m ∈ N^{II}).

$$\mathbf{x_m} = \sum_{j \in N^I} \mathbf{X_{mj}} + \sum_{j \in N^{II}} \mathbf{X_{mj}} + \mathbf{X_{mF}} \quad (8)$$

Accordingly, the output of one waste treatment sector m equals the sum of all output from sector m to all good sectors j (j ∈ N^I), plus the sum of all output from sector m to other waste treatment sectors j (j ∈ N^{II}), plus any external direct demand for output from sector m (Court, et al. 2015; Liao, et al. 2015; Nakamura, et al. 2007; Jensen, et al. 2013). Although it is reasonably logical to assume any good sector might have external direct demand for its output not being included in any other good or waste treatment sector, this seems rather unlikely for any waste treatment sector. In reality end-consumers rarely have a direct demand for waste output to use as input; however, it is hypothetically possible and therefore included in the mathematical summary of output analysis.

Equally to the output of goods and waste sectors, the output of a specific waste type k within the system can be analysed with k ∈ N^w.

$$\mathbf{x_k} = \sum_{j \in N^I} \mathbf{X_{kj}} + \sum_{j \in N^{II}} \mathbf{X_{kj}} + \mathbf{X_{kF}} \quad (9)$$

The overall output of one specific waste type k would accordingly be defined as the sum of the output of this waste type k flowing into good sectors j (j ∈ N^I), plus the sum of the output of waste type k going into waste treatment sectors j (j ∈ N^{II}), plus any external direct demand for output of the waste type k (Nakamura, Kondo, 2009; Liao, et al. 2015; Nakamura, et al. 2007). Again, the relevance of the direct demand of end-consumers for waste in reality might be questioned, however, the factor has to be included based on the theoretical possibility.

As a result of this extensive mathematical analysis, the input, output and waste flows can be analysed based on the real-life data for any region, industry or waste type. The overall goal for future developments, based on however positive or negative the results may be, has to be on reaching a status where the following condition is met or as closely met as possible:

Sum of all waste output = Sum of all waste used as input (10).

In a scenario like this, an economy, industry or region would achieve an overall neutral environmental balance minimising negative impacts on current as well as future prosperity while still satisfying customers' towards a more circular economy (Nakamura, Kondo, 2002; Nakamura, et al. 2007; Jensen, et al. 2013).

The WIO reveals the sales and purchasing patterns between industries and enables comparisons on environmental impacts between sectors (Court et al. 2015). Its unique feature is to quantify direct and indirect environmental effects throughout a products' supply chain capturing suppliers' influences on numerous levels (Hendrickson et al. 1998; Liao et al. 2015). Therefore, a link between the economic activities and their waste generation can be established and subsequent propositions to reduce or avoid waste can be made accordingly (Salemdeeb et al. 2016).

Data on regional real-waste flows was collected from The Environment Agency, UK. The companies in waste transportation and handling were identified based on the list of active companies active in the region collected from ORBIS. This data was then summarised to reconstruct waste streams in value (monetary units) as well as in reasonably accurate resource volumes. Two sets of data were generated per region, one for the listed input of waste and the other for the output. Further information on the waste were included through the European Waste Catalogue Code, the Waste Category and the reported volume in tonnes. For analysis, these data sets were then combined to create one table of waste flow information per region based on the mathematical procedure explained earlier (Nakamura and Kondo 2009; Nakamura and Kondo 2002; Miller and Blair 2009; Nakamura et al. 2007; Jensen et al. 2013).

4. Data mining, conditioning, and analysis

A data mining approach was used to identify patterns among the large sets of data collected from different publically available resources such as governmental database. Data were then conditioned and adjusted to be consistent to the chosen regional and industry parameters. Following this, relationships among the different variables were established. Suitable companies to be investigated were identified. To obtain a list of active companies in the North East region of England, the ORBIS database was used. This database, run by the Bureau Van Dijk corporation, aggregates public and private company data that is publically available and makes it easily accessible and adjustable (Bureau Van Dijk 2017). This search provided a list of 35,116 active companies with a postcode locating them in Durham or Darlington. This geographic restriction is solely made based on the amount of data to be used for testing the framework. To allow a first comparison, these results were measured against the respective outcomes of the re-applied analysis on the 69,476 active companies in the region of Newcastle.

To allow an analysis of the trade relationships within the chosen British regions, an investigation of the overall network of companies in these areas was important to develop a feeling for the regional economies. The companies were sorted into industries and sectors according to the NACE Codes, the Statistical Classification of Economic Activities in the European Community (European Parliament, 2006). To deepen the understanding of the regional situation the industry categories were summarised using the three-sector theory (Fisher 1935; Clark 1940). To enable a more detailed analysis, the companies were additionally sorted into sub-categories of Primary Industry - Raw Material, Secondary Industry – Manufacturing, Secondary Industry - Final Processing, Public Industry - Basic Service, Tertiary Industry - Basic Service and Tertiary Industry - Additional Service (Table 1). It was taken into account that in each category a number of companies were missing information on some key characteristics such as turnover or number of employees. Accordingly, these were sorted into the category n/a based on lack of information.

<<Include Table 1 about here>>

Overall, the regions showed a mix between sectors (Figure 3), although a striking number of companies were active in the tertiary sector providing the majority of turnover and jobs (Table 1). This showed that the regions had implemented changes reasonably well in relation to necessary structural changes to shift their focus away from mining and steel industry (Hodgson, Charles, 2009).

<<Include Figure 3 about here>>

The regional overviews showed that both areas had everything needed for a smooth run of companies' operations, primary industry of agriculture and mining, secondary industry of manufacturing of parts as well as final processing and tertiary industry of logistics and support companies as well as a public sector of overall support and infrastructure (Table 1, Figure 3). This structure suggested that a regional Circular

Economy could be possible as every level of the industry was present. The region of Durham and Darlington had 35,116 listed companies, the region of Newcastle had 69,476 companies which all qualified as waste producers, while simultaneously (waste-) transportation companies (NACE Code Divisions 38 and 39), waste handling companies (NACE Code Division 46) and treatment companies for hazardous and non-hazardous waste were present. Furthermore, all companies qualified as potential customers for recycled waste (Rowe et al. 2017).

To further analyse the circularity of the regional economies, an in-depth investigation of actual trade relationships and waste flows between the companies was needed. Trade relationships could best be analysed using the Waste Input-Output-Tables to compare values of exchanged goods between sectors divided into input and output (Hendrickson et al. 1998; Nakamura et al. 2007; Nakamura, Kondo, 2009; Salemdeeb et al. 2016; Court et al. 2015). Most of the previous research have used secondary data or bibliometric research when either analysing Circular Economy or Waste Input-Output-Tables (Winans et al. 2017; Jiaoa and Boons 2017; Geng et al. 2012; Andrews 2015). Primary data have rarely been used, which can be explained by the fact that a Waste Input-Output-Table would need extensive primary quantitative data, which most companies classify as internal data and are not prepared to share publically. As individual companies usually perceive this data as confidential internal information (Data Landscape, 2017), a regional Waste Input-Output-Table is not publically available. However, the Organisation for Economic Co-operation and Development (OECD) published a Waste Input-Output-Table for the whole of the United Kingdom based on data from 2011 (OECD.Stats 2011). This table served as a basis to investigate the monetary inter-sector relationships, which were then further broken down to the region of Durham and Darlington as well as the region of Newcastle.

Additionally, specific data on regional waste flows was needed to analyse the concrete potential for increased circularity within the chosen region. This most crucial set of information was not publicly available but was needed to conduct any meaningful analysis. For this research, the data on waste streams was provided by the Environment Agency's North East Area (Environment Agency 2017). Based on the aforementioned active companies in the investigated regions, relevant companies in waste transportation and handling were identified. These had to report to the governmental agency for record and supervision purposes. This data included volume and type of waste handled, where it geographically originated from, where it was transported to, and what was the company's overall capacity. This data was summarised according to the relevant regions and companies and was then used to reconstruct waste streams in the aforementioned monetary units as well as in reasonably accurate resource volumes. The data parameter was chosen for the complete calendar year of 2016 to ensure a full annual data set – allowing future comparative analysis of different regions or different time scales (Environment Agency 2017).

After relevant conversion of the national OECD list, it was broken down onto a regional level assuming that the proportional distribution of input and output in the regions Durham/Darlington and Newcastle were equal to the proportional distribution of input and output in the United Kingdom overall. To achieve this breakdown, the percentages of the total output generated by each sector were calculated row-wise. It is assumed, that 100 percent of the sector n/a came from and stays within that sector as no differing information was available. Similar assumptions were made for the output of the NACE Codes 97 to 99 as they were not listed in the OECD table. The proportional output calculated from the national trade relationships was then converted into monetary units for the sectors in the analysed region by multiplying the percentage with the total regional turnover of that industry sector (Table 2). These ratios did not change significantly between years and were therefore used as an indicator of the waste distribution between sectors (OECD.Stats 2006, OECD.Stats 2011). The monetary output of each territorial industry was hereby defined as the sum of the companies' turnovers according to the regional list of companies. Accordingly, the sum of all output from one industry to all other sectors was the total turnover taken from the list of companies. Likewise, the sum of all columns in the regional Waste Input-Output-Table plus taxes, but with subsidies on intermediate and final products deducted, was equal to the sectors' inputs. This was including the sectors' value added, as the turnover data used was needed to be subtracted to show only the sectors' inputs. To allow this, it was assumed that the proportional value added based on the input on a regional basis exactly mirrored the proportional value added on a national level.

<<Include Table 2 about here>>

To deepen the understanding of specific waste flows, a recalculation of the waste streams from monetary units in the regional Input-Output-Table into waste types and their volumes was needed. This only investigated the rows and columns of the regional Input-

Output-Table connected with waste handling, however, added detail to the monetary trade relationships listed by linking the flows back to the reported volume flows of waste.

5. Findings and Discussion

The aforementioned analysis of the regional companies, as well as the broken down Waste Input-Output-Table and the investigation of the regional waste streams, lead to various findings and levels of explanations. After analysing the companies in the chosen English regions, it is evident that every industry category according to the three-sector theory contributes towards the regional economy (Fisher 1935; Clark 1940). However, their impact and importance vary. Nonetheless, it is concluded that a regional Circular Economy was a possibility. The regional Waste Input-Output-Tables of inter-sector trade relationships based on the OECD.Stats (2011) tables show a regional sum of input that is smaller than the regional sum of output, as companies add value through their processes. The Input-Output-Table for Durham/Darlington also shows that about 55,054,000 Euros of value output from the agricultural sector stay within that sector, while only 190,000 Euros of value go into mining and quarrying (Table 2). Although this full Input-Output-Table will not be an exact match to the real regional network of relationships based on the assumptions used, the primary data would be required to be collected with a governmental authority to access internal company data successfully for better results to be obtained. However, the purpose of this research to generally introduce a methodology to measure the circularity of an economy and consequently quantify potential for improvement this regional Input-Output data is sufficiently met with the existing set of data.

Through the regional Waste Input-Output-Table it becomes obvious that every goods and service sector already has an input and output relationship with the waste handling and treatment sector. It can be seen in the Input-Output-Table rows listing the direction of output and columns representing the directions of input are filled according to exchanged values based on the aforementioned methodology and assumptions (OECD 2015; OECD.Stats 2011).

In general there are 89 companies within the region of Durham and Darlington invested in the waste-handling sector, listed with an overall annual capacity of 12,439,876 tonnes (Table 3). The waste reported as received in and removed from those sites is divided into hazardous, Household/Commercial/Industrial (HCI) and inert waste along with their respective quantities (Environment Agency 2017). A comparison of the overall waste input and output volumes allows conclusions to be drawn about the circularity of the region.

<<Insert Table 3 about here>>

In Durham and Darlington, the waste companies together maintain 3,318 waste handling sites from landfill to treatment and recycling with an overall annual handling capacity of 12,439,876 tonnes. Out of these sites, a striking number is already active in processing waste for re-usage: 507 sites are Materials Recycling Facilities (MRS) and 1,737 sites engage in waste treatment (Environment Agency 2017). This would suggest that within the region a reasonably effective circularity is already installed. This impression is further evidenced by evaluating the results of the waste stream analysis. In 2016, the reported regional waste streams show an overall input of 3,434,861 tonnes. Out of these, 968,783 tonnes were classified as hazardous, 1,519,248 tonnes as HCI and 946,829 tonnes as inert waste. In the corresponding reported waste output, the volume that left the waste sector was 1,035,069 tonnes, out of which 35,263 tonnes were identified as hazardous waste, 704,452 tonnes as HCI and 295,352 tonnes as inter waste (Table 3). Accordingly, the region has a waste input-output ratio of about 3:1.

In Newcastle there are 5,508 waste handling sites with an annual capacity of 18,114,747 tonnes (+45.62% compared to Durham/Darlington). In similar to the previously analysed region, a reasonable number of sites in Newcastle are actively involved in recycling (371 sites) and waste treatment (1,457 sites). The waste streams of 2016 show a reported input of 4,053,441 tonnes. This quantity was composed of 45,162 tonnes of hazardous waste, 2,469,194 tonnes of HCI and 1,539,085 tonnes of inert waste. The waste output from sites in Newcastle was 2,628,846 tonnes, out of which 23,392 tonnes were reported as hazardous, 1,962,041 tonnes as HCI and 643,412 tonnes as inert waste. Contrasting these reported waste streams, it can be noted that the percentage of waste leaving sites in Newcastle in relation to the intake is considerably higher than compared to the region of Durham and Darlington. This demonstrates a better recycling rate in Newcastle. It is equally important to note that the region of Durham and Darlington handled more hazardous waste than Newcastle in absolute terms as well as considerably more in terms of percentage to the total waste handled. While hazardous waste in Newcastle accounted only for about one percent of the total amount of waste handled (input and output) this waste category accounted for almost 23 percent of the total waste handled in Durham/Darlington (Table 3).

Some types of waste within this analysis seem to have a better ratio of circularity than others. In some site categories, 2016's annual output exceeds the input, indicating that some waste that entered the sites the year before was removed. However, in Durham/Darlington, there was a discrepancy between waste input and output where the input volume significantly exceeded the output volume (Figure 4). One example could be found in the metal scrap (ferrous and non-ferrous). According to the data set, about 212,538 tonnes of metal crap entered the regional Materials Recycling Facilities in Durham/Darlington in 2016, whereas only 69,167 tonnes left these sites in the same year. Although it is known that metal scrap is particularly subject to the storage and transfer between sites, the negative ratio of circularity highly influences the overall ratio and is therefore subject to further investigation (Table 4).

<<Insert Figure 4 about here>>

<<Insert Table 4 about here>>

To break this down to one waste type, an exemplary analysis was conducted of non-ferrous metal in Durham/Darlington. The overall input of this waste type into local waste handling sites was reported with a volume of about 104,204 tonnes. Out of these, 64,80 tonnes went directly to landfill and were consequently lost for recycling or re-use. However, the majority of 97,416 tonnes were received in Materials Recycling Facilities while the remaining 6,723 tonnes were transported into treatment sites (Environment Agency 2017).

It could be concluded from the analysis that the circularity of non-ferrous metal was observed be high as the majority of non-ferrous metal scrap was handled in sites associated with recycling and recovery. However, on simultaneous analysis of the reported output of non-ferrous metal, it was evident that only 5,674 tonnes left the sites in 2016 (Environment Agency 2017). This raises the question of what happened to the rest of the received non-ferrous metal. Even after considering the assumptions of potential double counting through transport between sites and storage into account, the discrepancy between the input and out remains prominent. Even a time delay of taking non-ferrous metal, treating it and then removing it again offers no reasonable explanation for the extent of the difference, especially as the ratio of the same waste type is considerably better in Newcastle (Table 4). To propose changes in the recycling practices to increase a region's sustainability, individual waste handling sites need to be analysed as to their circularity ratio and their recycling potential. However, to strengthen the accuracy of these results, further analysis with primary waste stream data is required in the future.

6. Conclusion and limitations

Recent debate on sustainable growth in literature shows a consensus on the vital role of waste and resource management in achieving a transition from a linear model to a circular one where the value of materials and resources are maintained in the supply chain (Salemdeeb et al. 2016). However, there are several challenges to Circular Economy such as regulatory, financial, information, and systemic barriers. Many of these barriers can be minimised through greater quantification of the UK's waste flows and by measuring its circularity. The aim of this research was to introduce a methodology to measure the overall circularity of an economy, a region or even a company. The benefit of combining a Waste Input-Output-Table with waste stream mapping is a holistic approach, which is not restricted to a limited number of variables. This work measures the overall waste arising in an exemplary region to then map and quantify its circularity. The results have shown that the British region of Durham and Darlington has a circularity of about 3:1, meaning that three tonnes of waste input into handling sites generate about one tonne of recycled and usable output. As a first benchmark, the same analysis in the region of Newcastle resulted in a circularity of about 2:1, and is therefore, considerably better than in Durham/Darlington. However, part of this difference may be explained by the unexpectedly high amount of hazardous waste handled in Durham/Darlington. This waste type is significantly harder to re-use or recycle than other waste types. The Waste Input-Output-Table and the waste stream mapping have also allowed for a categorisation of waste and an investigation of circularity of individual waste types outlining differences in the degree of circularity between categories.

Knowledge about sources of waste, their flows, and, usage has gained increasing importance in the context of rising global demand and limited natural resources. If sustainable economic growth is to be achieved a shift in priorities towards increased resource efficiency is needed. The concept of Circular Economy has been agreed to show a possible path (Elia et al. 2017; Ellen MacArthur Foundation 2015; Department for Environment, Food and Rural Affair 2015; Kristensen et al. 2016). This provided methodology is the first step towards measuring Circular Economy and consequently quantifying the potential to improve. However, this being the first analysis to quantify circularity within a region using a Waste Input-Output-Table and waste stream mapping little judgement of the regionally achieved circularity can be made. To assess the circularity ratios of about 3:1 and 2:1, more comparable analyses of different regions are needed to be conducted to establish a validated benchmark allowing an evaluation of how well a region performs. This research, therefore, establishes a foundation for further studies.

For this research, several limitations need acknowledgement. Some of these are the assumptions made to break down the national Input-Output-Table onto a regional level as input and output data is perceived as confidential information by companies. This limitation can only be avoided if an environment is created in which companies share this information, either based on legal requirement or on a voluntary basis of benchmarking. Additionally, the time gap between the data sets used needs addressing. The analysis is based on the most recently published data of the OECD of the year 2011, while the regional data set focuses on 2016. This time gap, however, does not undermine the results of the analysis as 2011 data set is only indirectly used. The 2011 data is solely converted into ratios to break down the regional data set. The exact data of 2011 is not used. These ratios are used under the assumption that between years the overall national waste distribution did not significantly change, which can be substantiated by calculating the same ratios with similar proportional results in the national data set of 2006 (OECD.Stats 2006). Another limitation lies within the lack of detail of the waste stream data set. Double counting, possible waste storage and inaccurate reported quantities reduce the concrete practical recommendations possible to increase the circularity. To progress beyond these inadequacies, companies need to be persuaded to disclose more detailed figures.

Despite these limitations, combining a Waste Input-Output-Table with waste stream mapping represents a step towards measuring Circular Economy, as well as better understanding of sources of waste and their flows. The example calculations in this research have shown potential to increase circularity and quantified benefits in order to convince stakeholders involved of the long-term advantages. This analysis could be followed by similar investigations of different regional and national economies to consequently propose steps to increase material efficiency and cooperation between companies and economies to increase circularity and sustainability to ensure future economic prosperity.

Notwithstanding these limitations, the outcome of this research would be useful for policy makers, manufacturing organizations, and waste management companies as it allows a benchmarking between regions of their level of circularity and accordingly a comparison between effectiveness of different regional regulations and their influence on sustainability and Circular Economy.

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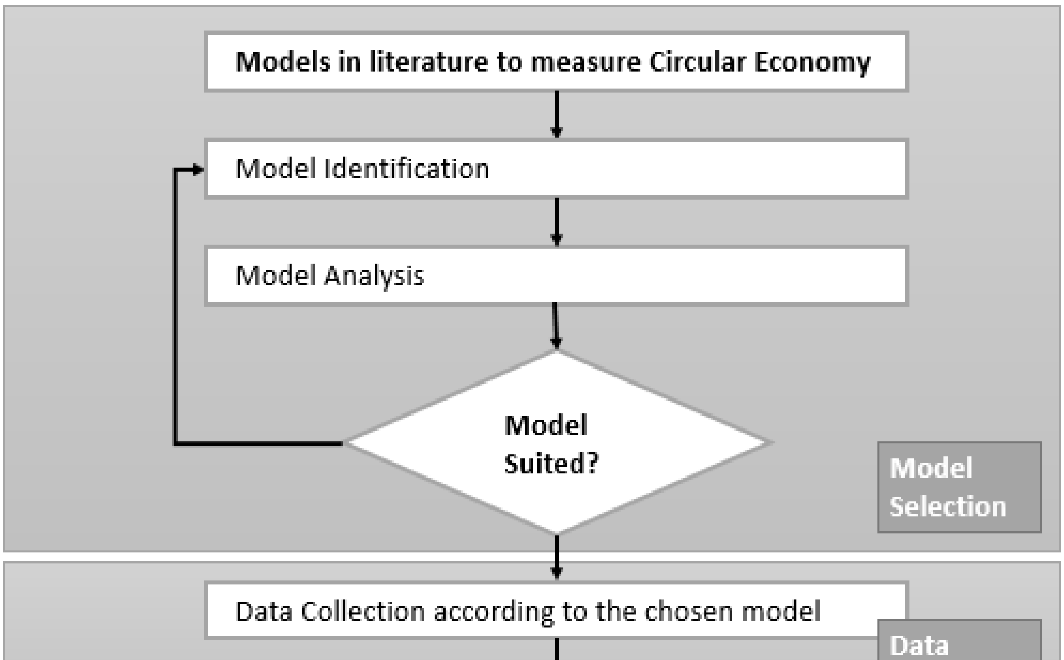

Models in literature to measure Circular Economy
Model Identification
Model Analysis
Model
Suited?
Model
Selection
Data Collection according to the chosen model
Data

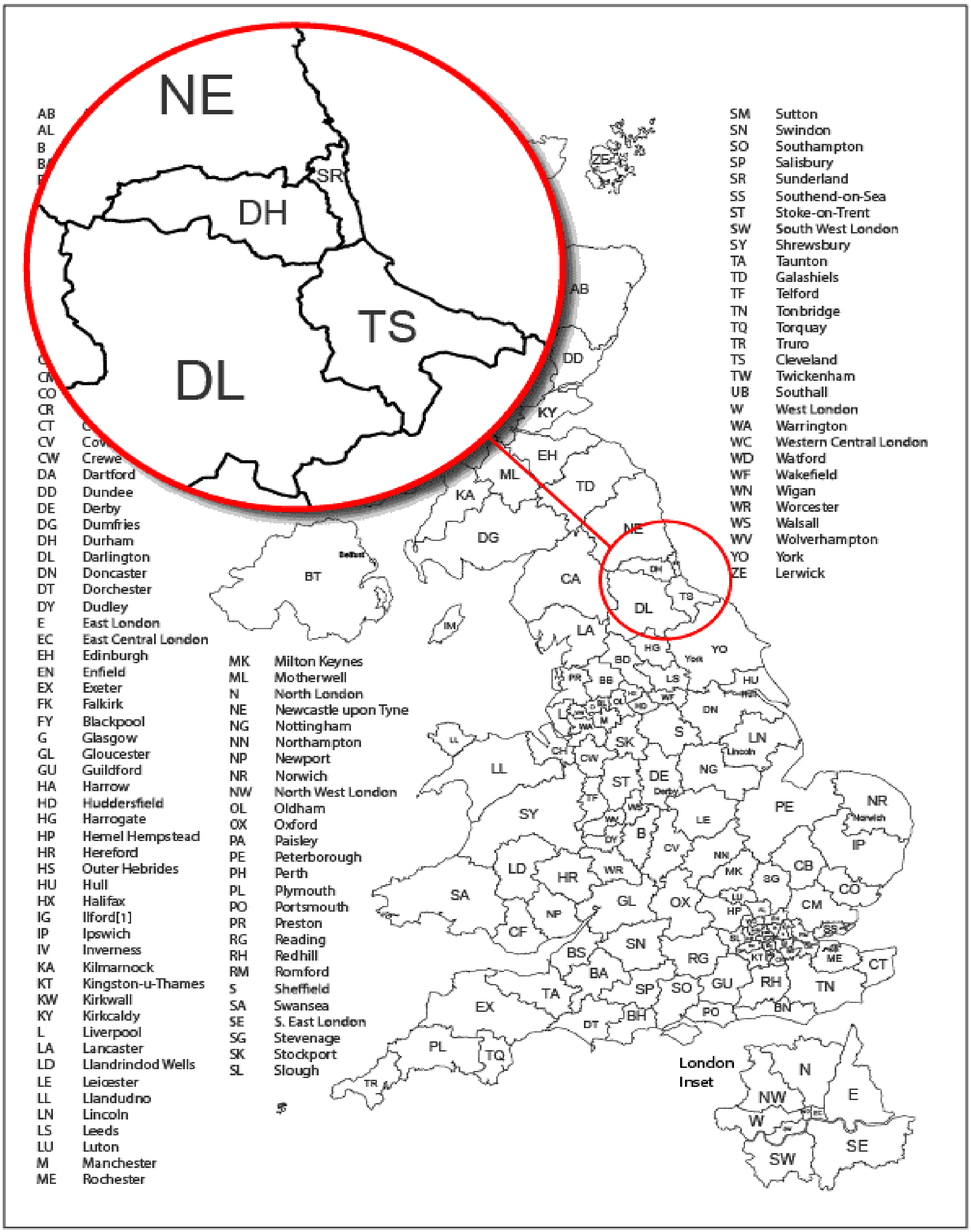

Figure 2: The North-East Region of England Considered for this Study

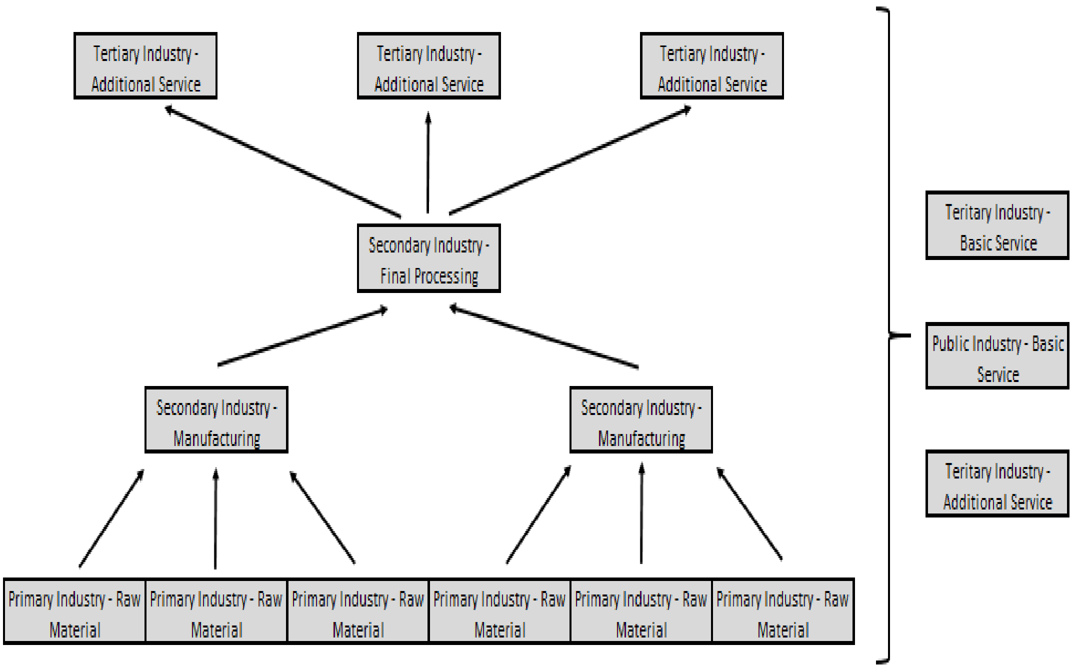

Figure 3. Network plan of overall regional companies' relationships

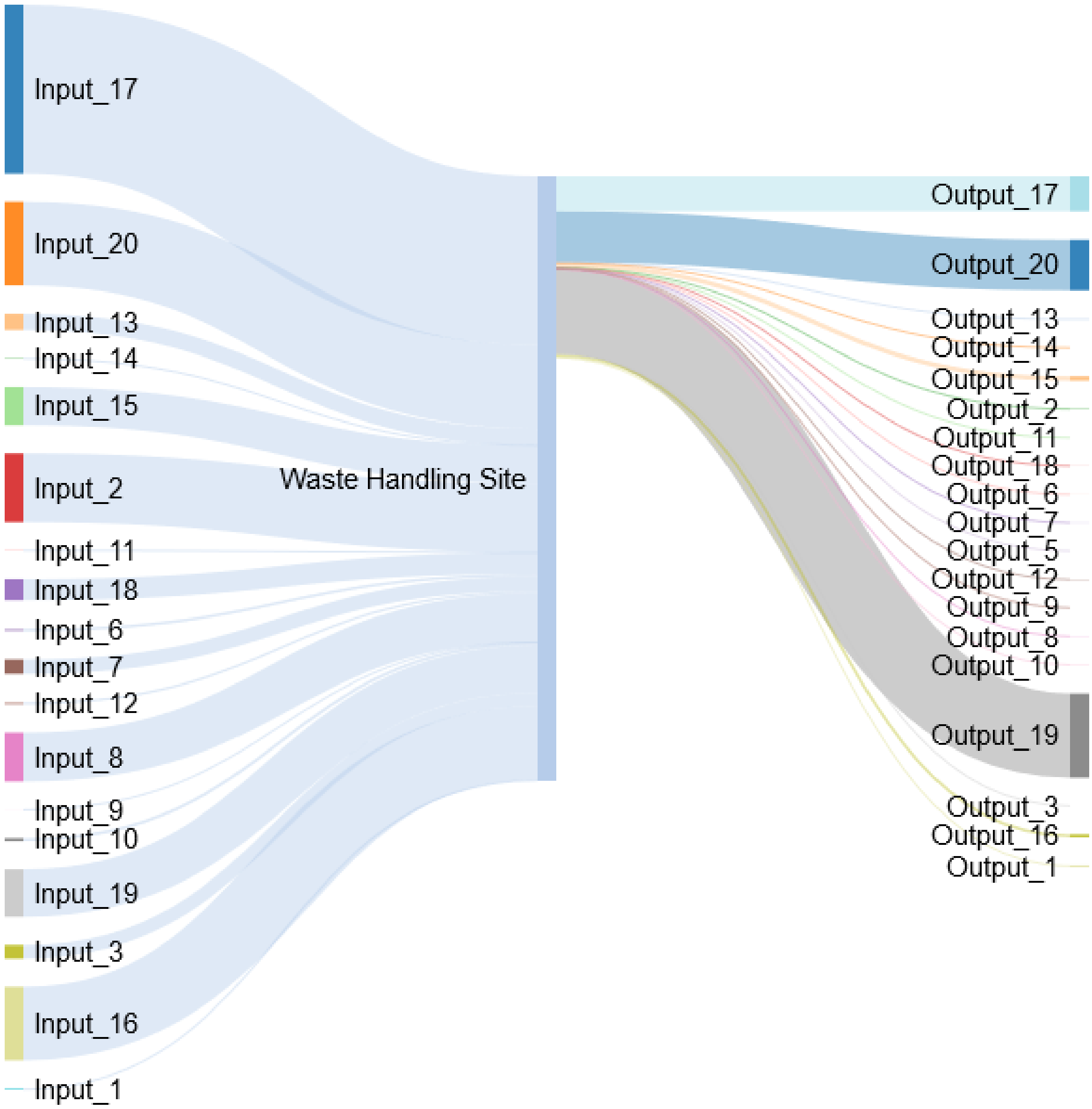

Figure 4: Discrepancy between total waste input and output based on EWC Chapter Codes

Table 1: Analysis of the regional companies				
NACE Codes	Industry Type	Number of Companies	Sum of Turnover (€)	Sum of Number of Employees
8 Categories; NACE Code Divisions 00 - 09	Primary Industry - Raw Material	1309	398333	2834
6 Categories; NACE Code Divisions 16 & 19 - 20 & 22 - 24	Secondary Industry - Manufacturing	303	607031	2548
20 Categories; NACE Code Divisions 10 - 15 & 17 - 18 & 21 & 25 - 32 & 41 - 43	Secondary Industry - Final Processing	5160	6117075	27175
5 Categories; NACE Code Divisions 35 - 39	Public Industry - Basic Service	274	2435822	8065
3 Categories; NACE Code Divisions 61 & 85 - 86	Tertiary Industry - Basic Service	2838	2142000	41245
46 Categories; NACE Code Divisions 33& 45 - 47 & 49 - 53 & 55 - 56 & 58 - 60 & 62 - 66 & 68 - 75 & 77 - 84 & 87 - 88 & 90 - 99	Tertiary Industry - Additional Service	21684	11677515	219538
Source: Analysis based on: Bureau Van Dijk, 2017; European Parliament, 2006; European Commission, 2008; Fisher, 1935; Clark, 1940.				

Table 2: Section of the regional Waste Input-Output-Table

	Variable	I/O Table Total							
	Country	GBR: United Kingdom							
	Time	2011							
	Unit	th Euro							
Column sector (to:)	NACE Codes	C01T05: Agriculture, hunting, forestry and fishing	C10T14: Mining and quarrying	C15T16: Food products, beverages and tobacco	C17T19: Textiles, textile products, leather and footwear	...	sector unknown	Sum = Turnover of all companies in that category	Sum (output)
NACE Codes		Section A	Section B	Section C - 10 to 12	Section C - 13 to 15	...	n/a		
TTL_C01T05: Agriculture, hunting, forestry and fishing	Section A	55.054,33	190,05	153.941,18	135,10	...	0,00	250.479,00	250.479,00
TTL_C10T14: Mining and quarrying	Section B	55,18	15.337,35	253,93	20,28	...	0,00	147.854,00	147.854,00
TTL_C15T16: Food products, beverages and tobacco	Section C - 10 to 12	34.129,89	930,66	179.410,79	1.854,38	...	0,00	605.689,00	605.689,00
TTL_C17T19: Textiles, textile products, leather and footwear	Section C - 13 to 15	103,82	20,56	54,25	1.640,71	...	0,00	5.162,00	5.162,00
...	...	...	...	...	...	...	...	...	...
sector unknown	n/a	0,00	0,00	0,00	0,00	...	207.719,00	207.719,00	207.719,00
Sum		297.001,62	242.850,00	887.560,10	93.424,07	...	207.719,00		
TXS_INT_FNL: Taxes less subsidies on intermediate and final products	constant % of sum of sectors	9.024,66	3.581,04	3.885,24	898,36	...	0,00		23.584.943,00
TTL_INT_FNL: Total intermediate and final expenditure at purchasers' prices (sum rows 9 to 43)	100% input + x% value added	306.026,29	246.431,05	891.445,33	94.322,43	...	207.719,00	24.607.760,49	
VALU: Value added [%]	turnover (inkl. Value added)	0,58	1,72	0,41	0,69	...	0,00		
VALU: Value added [th €]		111.761,61	155.882,97	260.867,66	38.423,24	...	0,00		
Sum	Input	194.264,68	90.548,07	630.577,68	55.899,19	...	207.719,00	13.376.055,10	

Source: Analysis based on: OECD.Stats, 2011, OECD, 2015

Table 3: Total Reported Waste (Tonnes)

	Input		Output	
Hazardous	968,783	28%	35,264	3%
Household/Commercial /Industrial	1,519,249	44%	704,452	68%
Inert	946,829	28%	295,353	29%
Total	3,434,861	100%	1,035,069	100%

Source: Analysis based on: Environment Agency, 2017

Table 4: Analysis of the WIO according to site category and site type

		Volume of waste stream in tonnes				
Site Category	**Site Type**	**Waste Received**	**Waste Removed**	**Total**	**Output - Input**	
Burial	Pet Cemetery	56	0	56	-56	
Combustion	Combustion	7.848	6.494	14.342	-1.354	
Composting	Composting (type unknown)	100	1.041	1.141	941	
Incineration	Co-Incineration	0	175	175	175	
Landfill	HIC LF	0	9.168	9.168	9.168	
Landfill	Inert LF	4.692	0	4.692	-4.692	
Landfill	Non Haz (SNRHW) LF	73.205	0	73.205	-73.205	x
Landfill	Non Hazardous LF	32.711	27.111	59.822	-5.599	
Mobile Plant	Mobile Plant - Landspreading	165	17.023	17.188	16.859	
MRS	Car Breaker	38.087	9.694	47.781	-28.392	x
MRS	Inert LF	41.602	0	41.602	-41.602	x
MRS	Metal Recycling	212.538	69.168	281.706	-143.371	x
MRS	Non-Haz Waste Transfer	16	0	16	-16	
MRS	Vehicle depollution facility	2.222	26.831	29.053	24.609	
On/In Land	Deposit of waste to land (recovery)	407	0	407	-407	
Processing	Non-Ferrous Metal reprocessing	0	225	225	225	
Storage	Storage - incinerator	1.496	88	1.584	-1.407	
Transfer	CA Site	115.921	52.496	168.416	-63.425	x
Transfer	Clinical Waste Transfer	115.876	591	116.467	-115.285	x
Transfer	Haz Waste Transfer	6.976	5.019	11.996	-1.957	
Transfer	Inert Waste Transfer	0	9.931	9.931	9.931	
Transfer	Non-Haz Waste Transfer	361.389	337.371	698.760	-24.017	x
Transfer	Non-hazardous & hazardous HWA Site	109	19.417	19.526	19.308	
Treatment	Biological Treatment	30	145	175	116	
Treatment	HCI Waste TS + treatment	162.364	41.221	203.585	-121.144	x
Treatment	HCI Waste TS + treatment + asbestos	47.398	31.538	78.936	-15.861	x
Treatment	Inert & excavation Waste TS + treatment	86	1.360	1.446	1.274	
Treatment	Material Recycling Facility (MRF)	792.636	144.075	936.711	-648.561	x
Treatment	Non-specified Treatment	534.517	9.719	544.236	-524.798	x
Treatment	Organic Chemicals	0	6.310	6.310	6.310	
Treatment	Physical Treatment	36.720	141.582	178.303	104.862	
Treatment	Recovery of Waste	322.584	23.797	346.381	-298.786	x
Treatment	Sewage sludge treatment	5.902	43.478	49.380	37.576	
Use of Waste	Reclamation	7	0	7	-7	
Use of Waste	Timber Manufacture	100	0	100	-100	
Total		**2.917.158**	**1.035.069**	**3.952.227**	**-1.882.090**	

Source: Analysis based on: Environment Agency, 2017.

Table 5: Analysis of the WIO according to site category and site type in Newcastle.

Newcastle						
		Volume of waste stream in tonnes				
Site Category	Site Type	Waste Received	Waste Removed	Total	Output - Input	
Composting	Composting (type unknown)	48.327,76	38.018,16	86.345,92	-10.310	
Composting	Composting in open windrows	24.803,43	187,18	24.990,61	-24.616	x
Incineration	Incineration	12.435,96	8.369,25	20.805,21	-4.067	x
Landfill	HIC LF		63.116,02	63.116,02	63.116	
Landfill	Inert LF	60.708,02		60.708,02	-60.708	x
Landfill	Non Haz (SNRHW) LF	1.356,72	13.005,00	14.361,72	11.648	x
Landfill	Non Hazardous LF	713.172,34	81.871,76	795.044,10	-631.301	x
Mobile Plant	Mobile Plant - Landspreading	91.532,79	91.532,79	183.065,58	0	x
Mobile Plant	Mobile Plant - Treatment	234,26	234,26	468,52	0	
MRS	Car Breaker	3.120,57	5.118,46	8.239,03	1.998	
MRS	Metal Recycling	191.381,31	167.438,51	358.819,82	-23.943	
MRS	Vehicle depollution facility	6.367,00	6.110,28	12.477,28	257	x
MRS	Metal Recyclcing	1.195,00	809,20	2.004,20	-386	
Processing	Non-Ferrous Metal reprocessing		6.614,14	6.614,14	6.614	
Processing	Paper Recycling	104.338,00		104.338,00	-104.338	
Storage	Storage - incinerator	192,67		192,67	-193	x
Storage	Storage - oils	170,56	177,56	348,12	7	
Transfer	CA Site	101.126,28	100.868,06	201.994,33	-258	
Transfer	Clinical Waste Transfer	119.740,41	75.673,90	195.414,31	-44.067	
Transfer	Haz Waste Transfer	380.608,51	400.412,54	781.021,05	19.804	x
Transfer	Inert Waste Transfer	48.048,77	45.236,14	93.284,91	-2.813	x
Transfer	Non-Haz Waste Transfer	975.096,09	827.968,97	1.803.065,06	-147.127	
Transfer	Non-hazardous & hazardous HWA Site	20.097,01	20.097,01	40.194,02	0	x
Transfer	Asbestos Waste Transfer Station	234,72	151,34	386,06	-83	
Treatment	Biological Treatment	33.136,55	59.791,53	92.928,08	26.655	
Treatment	HCI Waste TS + treatment	26.860,50	25.195,61	52.056,11	-1.665	x
Treatment	HCI Waste TS + treatment + asbestos	2.199,91	2.818,85	5.018,76	619	
Treatment	Inert & excavation Waste TS + treatment	242.052,45	33.655,74	275.708,19	-208.397	
Treatment	Material Recycling Facility (MRF)	216.034,24	158.739,31	374.773,56	-57.295	x
Treatment	Non-specified Treatment	19.106,71	16.398,00	35.504,71	-2.709	x
Treatment	Physical Treatment	162.107,57	143.648,96	305.756,53	-18.459	
Treatment	Recovery of Waste	184.888,69	177.122,54	362.011,23	-7.766	x
Treatment	Sewage sludge treatment	161.248,02	52.691,90	213.939,92	-108.556	
New	New Type	2.179,00	1.234,50	3.413,50	-945	x
N/a		99.339,26	4.538,91	103.878,17	-94.800	
Total		4.053.441	2.628.846	6.682.287	-1.424.595	x

Source: Analysis based on: Environment Agency, 2017.