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2 TABLE: LINKING WASTE GENERATION TO THE UK ECONOMY"  
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## 12 **1 Introduction**

13 The circular economy package was adopted in the EU in an attempt to boost competitiveness  
14 and generate sustainable growth (EC 2015c; EC 2015a; EC 2015b). This ambitious strategy is  
15 built on adopting a holistic approach by enhancing the production cycle and stimulating  
16 Europe's transition from a take-make-dispose model into a circular model. The UK has a unique  
17 economic structure, waste treatment capacities, and waste generation characteristics. This  
18 means that the UK faces unique challenges in shifting to a circular economy.

19 The UK government has recently released responses to the EU circular economy package,  
20 listing barriers to adoption (DEFRA 2015b; Environmental Audit Committee 2014; DEFRA  
21 2015a). These include regulatory, financial, information, and systemic barriers. Many of these  
22 barriers can be assisted through greater quantification of the UKs waste flows.

23 A consensus exists on the vital role of waste and resource management in achieving a  
24 transition from a linear model to a circular one where the value of materials and resources are  
25 maintained in the supply chain. However, in order to do so, effective strategies and plans can

26 only be designed and implemented based on a sound understanding of the issue. In order to  
27 address the above barriers and move towards this circular model, the UK must have greater  
28 quantification of waste flows, and better identification of existing disposal options. This will allow  
29 greater understanding of the current status and ultimately allow the introduction of effective  
30 management strategies.

31 Quantification of waste arisings in the supply chain represents a compelling challenge in our  
32 globalized and modern world; the supply chain of products is inter-connected and fragmented  
33 across different industrial sectors. Waste systematically emerges throughout the supply chain  
34 as a result of economic activities and trades (Kurz 2006; Beamon 1999; Parfitt et al. 2010). An  
35 example of this is a study conducted by the UK Waste and Resource Action Programme  
36 (WRAP 2013) examined food and drink waste arising in the supply chain. This study estimated  
37 that 13 Mt of waste is generated in the food and drink supply chain, 85% more than waste  
38 arisings in the post consumption stage.

39 Within the industrial ecological toolkit there are many modelling methods that enable the tracing  
40 of waste generation and resource flows within the (circular) economy. Two similar methods are  
41 Input-Output (IO) and Material Flow Analysis (Nakamura et al. 2007). In this study we suggest  
42 the use of waste IO analysis (WIOA) to quantify the economic and waste impacts in the UK  
43 (Nakamura & Kondo 2009).

44 IO analysis is an accounting procedure that was principally formulated by Leontief in the 1930s  
45 (Leontief 1936), to trace financial transactions and understand the interactions between  
46 industrial sectors, producers and consumers within an economy. The IO methodology has been  
47 previously used to couple financial information with physical waste data and to link waste  
48 arisings to economic activity, examples include: the regional WIO table of Wales (Jensen et al.

49 2011); the Dutch NAMEA (Haan & Keuning 1996); the German physical IO table (Stahmer et al.  
50 1998); the WIO table for Japan (S. Nakamura & Kondo 2002; Tsukui et al. 2015); Australia  
51 (Reynolds et al. 2014; Fry et al. 2015), Taiwan (Liao et al. 2015) and France (Beylot et al.  
52 2016).

53 This study introduces the first part of ongoing research: the development of a national UK WIO  
54 table. Linking 34 waste types to 21 UK industrial sectors, this paper introduces the first version  
55 of the UK WIO table that enables the quantification of waste arisings throughout the supply  
56 chain. The proposed WIO table is expected to be further developed and disaggregated to help  
57 identify current disposal options. Upon the completion of the project, the UK WIO table would  
58 provide a wider understanding of the issue and, consequently, assist in the economic and waste  
59 flow modeling of tailored interventions to tackle this issue and promote waste prevention and  
60 circular economy strategies.

## 61 **2 Methodology**

### 62 **Data Sources**

63 The WIO table was synthesized using data from two primary sources: financial data from the  
64 2010 UK Input Output Analytical Tables (IOATs) (ONS 2014), and waste data from the  
65 Environment Data Waste Centre (Eurostat 2011). The 2010 IOATs is the latest published table  
66 showing the composition of uses and resources across institutional sectors and the inter-  
67 dependence of industries within the UK national economy. Compiled in accordance to UK's  
68 Standard Industrial Classification 2007 (SIC 2007) for industries, the detailed version of the  
69 2010 IOATs have 114 industrial sectors. However, due to the unavailability of high-resolution  
70 waste arisings data, these industrial sectors were aggregated into 21 categories (Table 1). For  
71 this introductory model is one waste treatment sector (#38), the activity level of this waste

72 treatment sector is dependent upon the amount of waste treated. Aggregated categories  
73 were chosen to be compatible with other datasets used in this work. The WIO model introduced  
74 here is a single region model with a domestic technology assumption (i.e. the impact of import  
75 and export flows on waste arisings are not considered).

76 Waste generation data for the year 2010 was categorized into 34 waste types complying with  
77 the EWC-Stat (Eurostat 2010; Eurostat 2011). "Services" sector was disaggregated into 6 sub-  
78 sectors in accordance with DEFRA's survey of commercial and industrial waste arisings 2010  
79 (DEFRA 2011). All sectors were labelled based on the statistical classification of economic  
80 activities in the European community- NACE Rev. 2 (Eurostat 2008).

81 For the purpose of this study, we investigate the impact of direct and indirect waste arisings for  
82 each industrial sector using a hypothetical scenario: a final demand investment of £1 million.

83 **Table 1 Classification of industries.**

No.	SIC 2007	Sector	No.	SIC 2007	Sector
1	[1-3]	Agriculture, forestry and fishing	12	[31-33]	Manufacture of furniture; jewellery, musical instruments, toys; repair and installation of machinery and equipment
2	[5-9]	Mining and quarrying	13	[35]	Electricity, gas, steam and air conditioning supply
3	[10-12]	Manufacture of food products; beverages and tobacco products	14	[36-37,39]	Water collection, treatment and supply; sewerage; remediation activities and other waste management services
4	[13-15]	Manufacture of textiles and related products	15	[38]	Waste collection, treatment and disposal activities; materials recovery
5	[16]	Manufacture of wood and related products	16	[41-43]	Construction
6	[17-18]	Manufacture of paper and paper products; printing and reproduction of recorded media	17	[45-47]	Retail and Wholesale
7	[19]	Manufacture of coke and refined petroleum products	18	[55-56]	Hotels & Catering
8	[20-22]	Manufacture of chemical, pharmaceutical, rubber and plastic products	19	[84, 86-88]	Public Administration and social work
9	[23]	Manufacture of other non-metallic mineral products	20	[85]	Education
10	[24-25]	Manufacture of basic metals and fabricated metal products, except machinery and equipment	21	[49-53]	Transport and storage
11	[26-30]	Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles and other transport equipment	22	[58-82, 90-96]	Other services

84

85 **IO methodology**

86 This WIO table's mathematical structure is based on the principles of the IOA (Miller & Blair  
87 2009). In order to link economic activities with waste arisings, we use the original extended  
88 model to define a matrix of environmental outputs – waste generation in this study (Hendrickson  
89 et al. 1998). In our study, total, direct and indirect waste arisings in the supply chain can be  
90 calculated using Eq.(1), Eq.(2) and Eq.(3), respectively. However, as per the WIO construction  
91 of Nakamura and Kondo (2002, 2009), the waste treatment sector was excluded from the  
92 calculation of multipliers (A and L). Data sources used in the model are available in the

93 supplementary file (see Table 2). To validate our results the multipliers were also calculated  
94 using a WSUT framework (Lenzen and Reynolds 2014).

95  $V = LY$  Eq.(1)

96  $L_{total} = W(I - A)^{-1}$  Eq.(2)

97  $L_{direct} = W(I + A)$  Eq.(3)

98  $L_{indirect} = W[(I - A)^{-1} - (I + A)]$  Eq.(4)

99 Where,

100  $V$  is a vector listing the waste arisings (tonnes) generated as a result of final demand ( $Y$ ).

101  $Y$  is a vector representing the final demand (£ million).

102  $L$  represents waste arisings associated with the supply chain.

103  $W$  is a coefficient matrix that represents waste arisings at each stage per monetary unit of  
104 output.

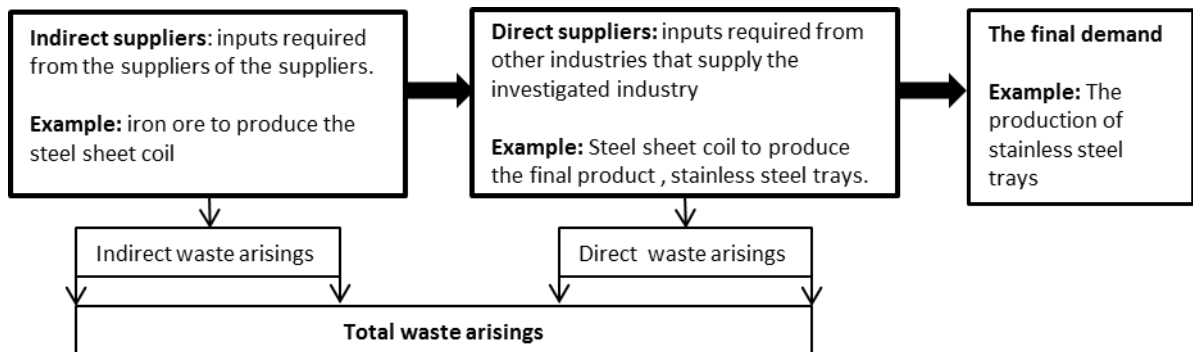
105  $(I-A)^{-1}$ . Leontief inverse coefficient matrix which is based on the 2010 UK Input Output Analytical  
106 table compiled in this work.

107 **Table 2 List of tables available in the supplementary file.**

Table no.	Data	Description
A(1)	The 2010 UK IOATs	The 2010 Input-Output Analytical Table aggregated into 21 industrial sectors.
A(2)	Final demand table	Consists of final consumption expenditure, cross capital formation, and exports of goods and services.
A(3)	Waste arisings table	Waste quantities generated in 2010
A(4)	Waste arisings multipliers table	Waste quantities generated for each £1 million from final demand
A(5)	Leontiff's inverse $(I-A)^{-1}$	A square matrix describes the relationship between total consumption and final demand
A(6)	Waste arisings associated with the whole supply chain (L)	Represents waste arisings associated with the supply chain.
A(7)	Waste arisings as a result of a final demand of £1 in each sector	Quantities of waste arisings (tonne) in the supply chain based on a final demand of £1 million in each industrial sector. 7a total, 7b direct supply chain and 7c waste generation rates per £1m of final demand for each industrial sector.

108 **Direct vs. indirect waste arisings**

109 The power of the WIO methodology applied in this study is the ability to capture both direct and  
 110 indirect waste arisings across the supply chain. Direct waste arisings are associated with  
 111 suppliers who directly supply the industry under investigation while indirect suppliers are those  
 112 that do not directly supply the industry but are suppliers to the suppliers of the industry, referred  
 113 to as indirect suppliers of first level, second level ...etc. Figure 1 illustrates the relationship  
 114 discussed above and provides an example to elaborate the relationship between total, direct  
 115 and indirect waste arisings.



116

117 **Figure 1 Direct and indirect suppliers and total waste arisings.**

118 **3 Results and discussion**

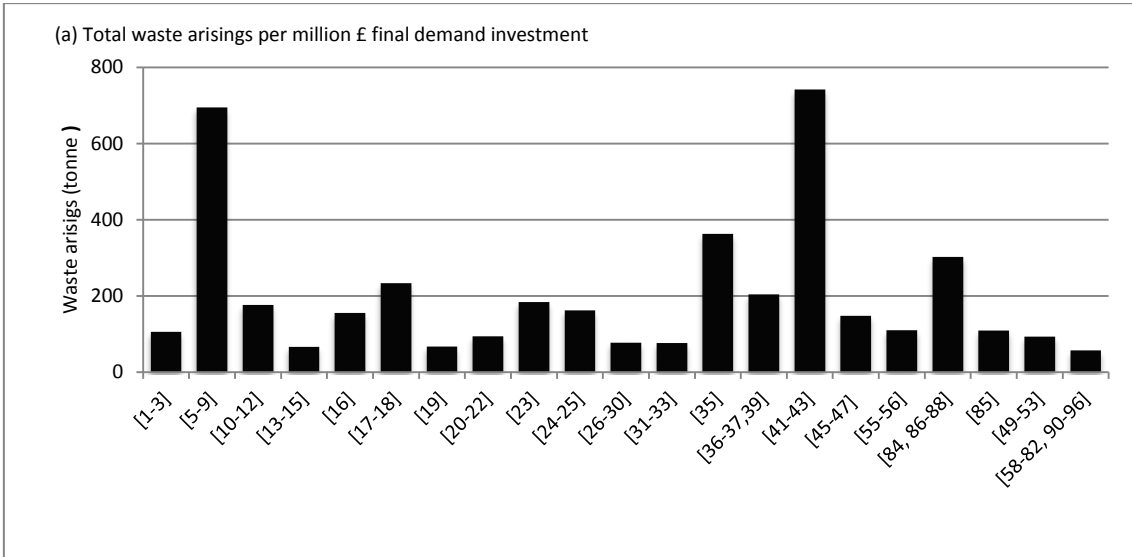
119 Results show that the construction sector has the highest waste generation rate (742 tonne)  
 120 followed by the mining and quarrying industry (694 tonne). Detailed results of waste arisings  
 121 quantities and the type of waste for all 21 industrial sectors are available in the supplementary  
 122 file, Table A(7). Figure 2(a) aggregates waste generation rates per £1m of final demand for  
 123 each industrial sector.

124 In regards to waste arisings in the direct and indirect supply chain, Figure 2 (b) shows large  
 125 variations in the contribution of indirect waste arisings across industrial sectors; it ranges from  
 126 13% in the mining and quarrying industry to 48% in the manufacturing of electronics. Results  
 127 quantitatively confirm that sectors with a long supply chain (i.e., manufacturing and services  
 128 sectors) have higher indirect waste generation rates compared to industrial primary sectors  
 129 (e.g., mining and quarrying) and sectors with a shorter supply chain (e.g., construction).

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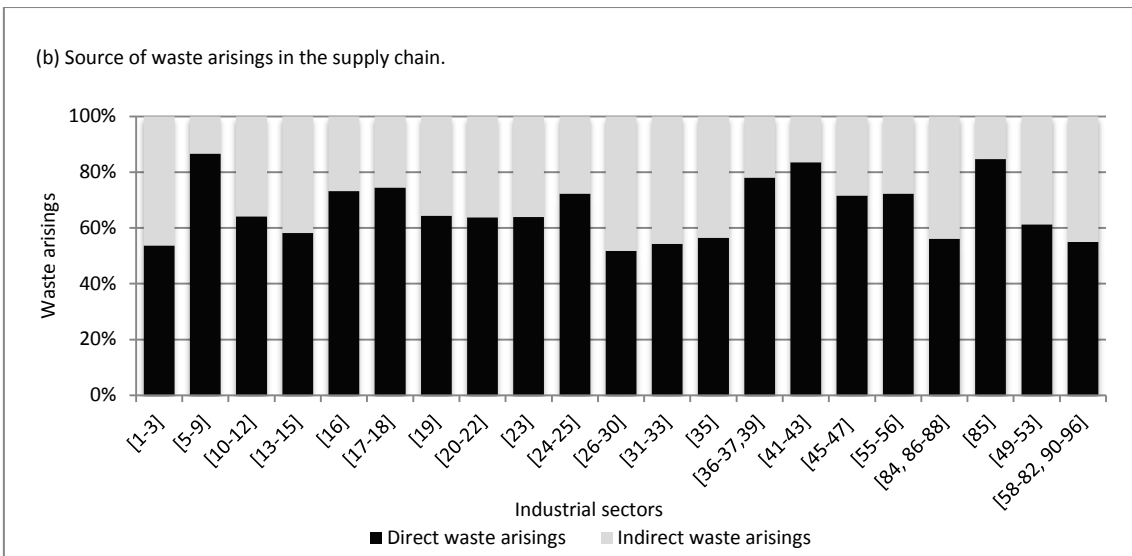
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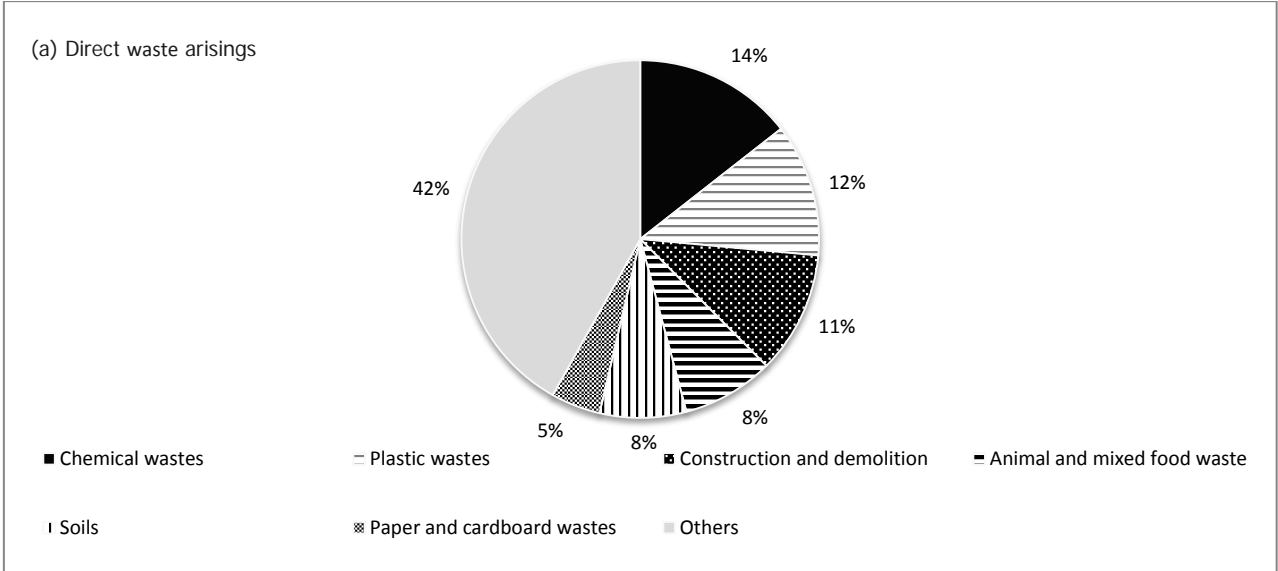
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**Figure 2 Total waste arisings per million £ of final demand investment (a) and its source (b) throughout the UK supply chain.**

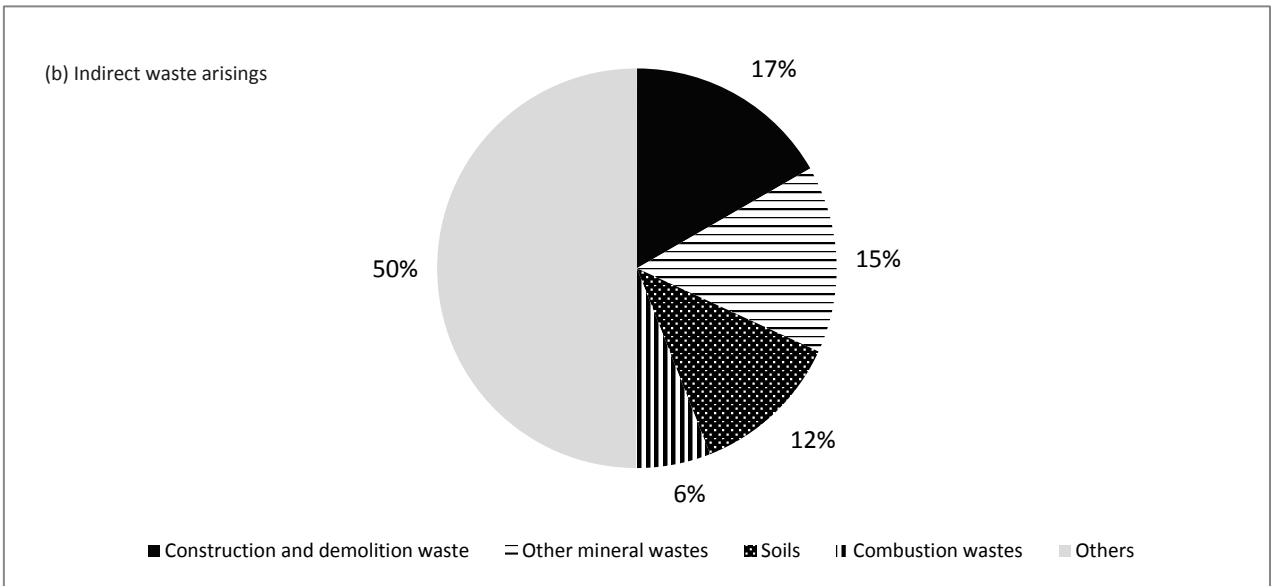
In order to demonstrate the power of the WIO table, we also investigate types of waste generated in both the direct and indirect supply chain of the agricultural sector (Figure 3). In the direct supply chain, Chemical wastes, generated due to the production and use of fertilizer and other chemical-based products, are attributed to more than 14% of direct waste arisings. Plastic

139 and paper and cardboard waste, representing packaging waste, are accountable for 12% and  
140 4.5% respectively. Figure 3(a) shows waste categories with generation rates that are greater  
141 than 5%. On the other side, waste from construction and demolition activities and mineral waste  
142 contribute 17% and 15% each to indirect waste arisings associated with the agricultural sector  
143 (Figure 3(b)). Other waste categories with significant generation (i.e., >5%) rates include soil  
144 and combustion waste.

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**Figure 3 Types of waste arisings in both direct (a) and indirect (b) supply chain of the agricultural sector. Other mineral wastes is a Eurostat waste-category including the following waste streams: asbestos, blasting wastes and other mineral waste originate from mining, quarrying and the treatment of minerals, manufacture of construction materials and casting processes Eurostat (2010).**

153 **4 Conclusions**

154 The aim of this paper was to introduce the first version of the UK WIO table that could be used  
155 to investigate waste arisings in the supply chain. The power of the current version of the WIO  
156 table is its ability to capture waste generation in the direct and indirect supply chains. Results  
157 have shown how sectors with a long supply chain (i.e. manufacturing and services sectors) tend  
158 to have higher indirect waste generation rates compared to industrial primary sectors (e.g,  
159 mining and quarrying) and sectors with a shorter supply chain (e.g, construction). The WIO  
160 table has also enabled the disaggregation of waste generation data into different waste  
161 categories.

162 Waste policy is often developed for specific waste streams or for specific economic sectors. The  
163 development of current waste policies seldom takes into account the effects of changing  
164 demand and production processes of one economic sector upon waste generation in another.  
165 This level of planning is required if a circular economy is to become a reality. The quantification  
166 provided in this paper is the first step towards more comprehensive waste policy. The UK WIO  
167 allows for the examination of waste generation hotspots, and the quantification of changes to  
168 final demand.

169 Several limitations to the first version of the WIO table need to be acknowledged. First, the  
170 current version doesn't provide any additional information about the final status of waste  
171 generated and its disposal option, whether recycled or landfilled. This major limitation is  
172 expected to be addressed in the second version of the WIO table to reflect recycling activities in  
173 the model in the same way as previous literature (Nakamura & Kondo 2002; Lenzen &  
174 Reynolds 2014; Nakamura & Kondo 2009). Second, the model is based on a top-down,  
175 economy-wide approach aggregating the whole economy into only 21 industrial sectors.

176 Although it would produce accurate and correct data in the sectorial level, it cannot distinguish  
177 sufficiently product groups of individual companies.

178 Notwithstanding these limitations, the introduction of the first version of the WIO table  
179 represents a step towards a better understanding of the flow of the waste. Specifically, this  
180 current UK WIO has allowed quantification of both direct and indirect waste flows for the UK  
181 economy. This work is expected to be followed up by disaggregating the waste sector into  
182 various industries, thus unlocking the “blackbox” representation of the waste sector.  
183 Consequently, this would lead to a better understanding of waste and resource flows in the  
184 supply chain.

185 **5 Associated content**

186 Supplementary data to this article can be found on-line.

187 **6 Declaration of conflicting interests**

188 The authors declare that there is no conflict of interest.

189 **7 Acknowledgements**

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193 **8 References**

194 Beamon, B.M., 1999. Designing the green supply chain. *Logistics Information Management*,  
195 12(4), pp.332–342.

196 Beylot, A. et al., 2016. A consumption approach to wastes from economic activities. *Waste*  
197 *Management*. Available at:  
198 <http://linkinghub.elsevier.com/retrieve/pii/S0956053X1630023X>.

199 DEFRA, 2011. *Survey of commercial and industrial waste arisings 2010*, London: Department  
200 for Environment, Food and Rural Affairs.

201 DEFRA, 2015a. UK response to European Commission consultation of member states on the  
202 circular economy. , pp.1–19.

203 DEFRA, 2015b. UK response to European Commission public consultations on the circular  
204 economy and on the functioning of waste markets. , pp.1–5.

205 EC, 2015a. *Amending Directive 2008/98/EC on waste*, Brussels: European Commission.

206 EC, 2015b. *Amending Directive 94/62/EC on packaging and packaging waste*, Brussels,:

207 European Commission.

208 EC, 2015c. *Closing the loop - An EU action plan for the Circular Economy*, Brussels,: European  
209 Commission.

210 Environmental Audit Committee, 2014. Growing a circular economy: Ending the throwaway  
211 society. , (July), p.43.

212 Eurostat, 2011. Generation of waste. Available at: <http://epp.eurostat.ec.europa.eu/> [Accessed  
213 November 1, 2015].

214 Eurostat, 2010. *Guidance on classification of waste according to EWC-Stat categories*  
215 *supplement to the manual for the implementation of the regulation ( EC )*, Brussels:  
216 Commission of the European Communities.

217 Eurostat, 2008. *NACE Rev. 2: statistical classification of economic activities in the European*  
218 *Community*, luxembourg: Office for Official Publications of the European Communities.

219 Fry, J. et al., 2015. An Australian Multi-Regional Waste Supply-Use Framework. *Journal of*  
220 *Industrial Ecology*, 00(0), p.n/a–n/a.

221 Haan, M. De & Keuning, S.J., 1996. Taking the environment into account: The NAMEA  
222 approach. *Review of Income and Wealth*, 42(2), pp.131–148.

223 Hendrickson, C. et al., 1998. Economic Input-Output Models for Environmental Life-Cycle  
224 Assessment. *Environmental Science & Technology Policy Analysis*, 32(7), p.184A–191A.  
225 Available at: <http://www.ncbi.nlm.nih.gov/pubmed/21650957>.

226 Jensen, C.D. et al., 2011. Responsibility for Regional Waste Generation: A Single-Region  
227 Extended Input–Output Analysis for Wales. *Regional Studies*, pp.1–21.

228 Kurz, H.D., 2006. Goods and bads: sundry observations on joint production, waste disposal,

229 and renewable and exhaustible resources. *Progress in Industrial Ecology, An Int. J.*, 3(4),  
230 pp.280–301.

231 Lenzen, M. & Reynolds, C.J., 2014. A Supply-Use Approach to Waste Input-Output Analysis.  
232 *Journal of Industrial Ecology*, 18(2), pp.212–226.

233 Leontief, W.W., 1936. Quantitative Input and Output Relations in the Economic Systems of the  
234 United States. *The Review of Economics and Statistics*, 18(3), pp.105–125.

235 Liao, M. et al., 2015. Identification of the driving force of waste generation using a high-  
236 resolution waste input–output table. *Journal of Cleaner Production*, 94, pp.294–303.  
237 Available at: <http://www.sciencedirect.com/science/article/pii/S0959652615001067>  
238 [Accessed April 12, 2016].

239 Miller, R. & Blair, P., 2009. *Input-Output Analysis: Foundations and Extensions* 2nd ed., New  
240 York: Cambridge University Press.

241 Nakamura, S. et al., 2007. The Waste Input-Output Approach to Materials Flow Analysis.  
242 *Journal of Industrial Ecology*, 11(4), pp.50–63.

243 Nakamura, S. & Kondo, Y., 2009. *Waste Input-Output Analysis: Concepts and Application to*  
244 *Industrial Ecology* 1st ed., Berlin: Springer.

245 Nakamura, S. & Kondo, Y., 2002. Waste input-output model: concepts, data, and application. In  
246 *Inter-disciplinary studies for sustainable development in Asian countries*. Keio: Keio  
247 University, pp. 6–25.

248 Nakamura, S. & Kondo, Y., 2002. *Waste Input-Output Model: concepts, data, and application*,  
249 Keio University.

250 ONS, 2014. *United Kingdom input-output analytical tables 2010*, Newport: Office for National



251 Statistics.

252 Parfitt, J., Barthel, M. & Macnaughton, S., 2010. Food waste within food supply chains:  
253 quantification and potential for change to 2050. *Philosophical transactions of the Royal*  
254 *Society of London. Series B, Biological sciences*, 365(1554), pp.3065–81. Available at:  
255 [/pmc/articles/PMC2935112/?report=abstract](https://doi.org/10.1098/rstb.2010.0187).

256 Reynolds, C.J., Piantadosi, J. & Boland, J., 2014. A Waste Supply-Use Analysis of Australian  
257 Waste Flows. *Journal of Economic Structures*, 3(5).

258 Stahmer, C., Kuhn, M. & Braun, N., 1998. *Physical input-output tables for Germany. Eurostat*  
259 *working paper no. 2/1998/B/a*, Luxembourg: European Commission.

260 Tsukui, M., Kagawa, S. & Kondo, Y., 2015. Measuring the waste footprint of cities in Japan- a  
261 interregional waste input–output analysis.pdf. *Journal of Economic Structures*.

262 WRAP, 2013. *Estimates of waste in the food and drink supply chain*, Banbury, Oxon: Waste and  
263 Resources Action Programme.

264