Waste Input-Output tables as an effective tool to examine circularity in production processes: evidence from Italy

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Abstract

Achieving circularity in economic processes is recognised as one of the most important challenges of the modern developed economy. However, for the Circular Economy Action Plan to be effective, a greater understanding of the link between economic activities and waste generation is required. Indeed, increasing resource efficiency, preventing waste generation, and using waste as a resource are at the heart of the circular economy with considerable potential to reduce environmental pressure. Circular strategies and business models can also help alleviate the growing concern over dependence on imported resources and access to critical raw materials, some of which play a key role in the development of renewable and low-carbon energy technologies.

The aim of this paper is to propose the Waste Input Output table for the Italian economy, linking data from waste generation sources to the national and territorial economic accounts. The availability of a unique framework waste input-output table will make it possible to examine different aspects of waste accountability, starting on whether and to what extent the length of the supply chain affects the waste generation rate and to better understand the flow of resources through the various supply chains up to the estimation of direct and indirect sources of waste at single industrial level, industry-output waste coefficients and impact multipliers.

Keywords: Input-Output Analysis, circular economy, multipliers, national accounts, official data.

1.Introduction

Circular economy (CE) is a concept officially adopted and promoted by the EU – within two Circular Economy Action Plans (CEAPs) in 2015 and 2020 (European Commission, 2015; 2020) – as well by other modern developed and developing economies and international official institutions with the aim and responsibility to tackle multiple challenges regarding the scarcity of natural resources, climate change and other critical socio-economic issues, related to the achievement of the United Nations (UN) Sustainable Development Goals (SDGs). The traditional linear “take-make-dispose” model (Kirchher et al, 2023) has accelerated the development of the global economy and advanced overall life standards in the past decades, even if it has been recognized that this development model has profound negative impacts on the environment, society, and economy.

CE provides an economic system with the alternative flow model of materials. Unlike the traditional economic approach, the CE model focuses on the reuse, remanufacturing, refurbishment, repair, cascading and upgrading of materials (Korhonen et al, 2018) which are in the formats of products, components, and raw materials. However, achieving circularity in economics processes is a complicated and challenging task. Scholars have also identified some challenges and limits in the practical application of the concept (Korhonen et al., 2018), which include, spatial and temporal system boundaries as well as governmental and management challenges concerning inter-sectoral and inter-organizational material and energy flows. On the other hand, there are other examples of achieving environmental and social results in local and regional economies which have led, directly or indirectly through supply chains, value chains, or product life cycles, into other problems in other locations (Korhonen et al., 2004).

Waste management falls into one of the above-mentioned limitations. According to the European Commission, approximately 5 tonnes of waste is produced annually in Europe per capita but only 38% is recycled; furthermore, over 60% of household waste still goes to landfill in some European countries. In the second European CEAP that has been adopted since 2020, improving waste management was set as one of the main objectives for the sector of waste and recycling (European Commission, 2020). In the study of UK waste, Salemdeeb et al. (2016) has argued that quantification of waste arisings in the supply chain is a compelling challenge due to our highly globalized and modern world. Products nowadays are highly interconnected, and a final product resulted from different industrial sectors of our supply chains. To achieve the successful transition from a linear model to circular model, a mapping of waste generation and treatments is essential (Salemdeeb et al., 2016) also in terms of disentangling for each economic activity the direct and indirect sources of waste.

In the process of exploring this mapping process, much research has pointed towards the Input-Output (IO) model, also developed together with Life Cycle Assessment (LCA) analysis as well as by referring to official sources of environmental statistics therefore leading to the Environmental Extended IO Analysis (Çetinay et al, 2020), within which the specific Waste IO (WIO) tables can be included. Relevant examples can be found in the analysis of UK (Salemdeeb et al., 2016), Wales (Jensen et al., 2013), the National Accounting Matrix including Environmental Account (NAMEA) approach for the Netherlands (De Haan and Keuning, 1996), Germany (Radermacher and Stahmer, 1998), Japan (Nakamura and Kondo, 2002b), Australia (Reynolds, 2013) and Taiwan (Liao et al., 2015).

The aim of this paper is to obtain and examine the WIO table for the Italian economy, linking data from waste generation sources to national economic accounts within the methodological framework initially formulated by Leontief (Leontief, 1936) and presented for the waste management issues by Nakamura (1999) and Nakamura and Kondo (2002a). By referring to harmonised sources of data it is possible to examine different aspects of waste accountability, starting on whether and to what extent the length of the supply chain affects the waste generation rate and to better understand the flow of resources through the various supply chains – in terms of both direct and indirect up to the estimation of industry-output waste coefficients and impact multipliers.

The remainder of this paper is structured as follows. Section 2 briefly summarises the existing literature (both linking CE to waste resources as), the data sources and the method used. Section 3 presents some provisional results, while Section 4 highlights the potential of this tool of analysis and the ongoing research.

2. Materials and Method

2.1. Circular Economy, Waste and IO Analysis

The circular economy framework emphasizes the importance of closing material loops, reducing waste generation, and promoting resource efficiency. IO analysis provides a valuable tool for assessing the potential of circular economy strategies and quantifying their impacts on waste generation and resource consumption.

Focusing specifically on the analysis of waste arising in industrial sectors, Nakamura et al. (2002b), pioneered the introduction of the WIO approach to the flows of goods and waste. In this study, the

WIO table for Japan, was aggregated to 13 industrial sectors, 3 treatment methods, and 13 types of waste; therefore, the mapping of waste groups to waste treatment methods was realized and the corresponding change of economic impacts could be observed by a given change in the input coefficients (Nakamura et al., 2002). The study by Salemdeeb et al (2016) – on which most of the analysis of this paper have been inspired - captured both direct and indirect waste arisings across the supply chain with results showing how sectors with a long supply chain, such as manufacturing and services industries, tended to have higher indirect waste generation compared with the primary industrial sectors like mining and industry with a shorter supply chain such as construction. For Portugal, Barata (2002) pointed out that IO analysis revealed the direct and indirect interactions of waste in the national economy. In this analysis, the IO approach was able to merge the different economic and environmental dimensions as well as to integrate the structure of different industrial sectors and levels of final demand with total waste generation, hazardous waste generation and landfill consumption (Barata, 2002). In Australia, the true scale of the food waste generation remained unclear due to the lack of information regarding where the waste was generated, what the waste was composed of, or how it was treated (Hawkins, 2006) until the application of LCA and Material Flow Analysis (MFA) which allows a clearer understanding of the waste streams and how the waste can become a resource. Reynolds (2013) implemented Waste Supply-Use Table (WSUT) inspired from Nakamura's WIO into monetary and physical waste flow systems in Australia; his framework explained the treatment methods and waste type in gross and net terms and allowed the separate analysis on the waste generation and the recycling (Reynolds, 2013). In Taiwan, Liao et al (2015) combined the WIO and supply chain analysis in such a way to be able to allocate the critical industries of high requirement on waste treatment capacity, meanwhile, clarified both consumers' and suppliers' responsibilities towards sustainable consumption and production (Liao et al, 2015).

In Italy, the implementation of the IO approach to waste management is limited. Indeed, Ali et al. (2018) discovered some potential relationships between the economic activities and carbon-and-water footprint in Italy with the IO approach. They have demonstrated that a huge amount of carbon emissions was related to international trade and the fastest growth in water use was related to imports in Italy (Ali et al., 2018). As for the waste management issue, Ripa et al (2016) using the Life Cycle Assessment approach, have explored the solid waste management system and its impacts on the environment in the Metropolitan City of Naples; their work allowed the identification of critical driving factors of the waste and the potential improvement strategies, but also reminded that the improvement in a single sector would not be enough to contribute to all impact categories, but might shift the burden from one to the other; in another word, waste management must be integrated with all material flows in the society (Ripa et al, 2016). Indeed, the circular economy has been developed and implemented to increase resource efficiency, to prevent waste generation, and to use waste as a resource. Circular strategies and business models can also help alleviate the growing concern over dependence on imported resources and access to critical raw materials, some of which play a key role in the development of renewable and low-carbon energy technologies.

2.2. Data sources

With the aim of obtaining the Waste IO (WIO) table for Italy we referred to two sources of data. Firstly, financial data (in million Euro) were obtained from the Italian Input Output (IO) symmetric table constructed by the Italian National Statistical Office (ISTAT) while waste data were obtained from the Environment Data Waste Centre produced by Eurostat. The IO tables for Italy are available up to the year 2019 while data on waste are available every two years from 2004 up to 2020. As a result, to select the same period of time for both financial and waste data we referred to the year 2018 as the latest published table and statistics showing – on one hand – the composition of uses and resources across institutional sectors and the inter-dependence of industries within the Italian national economy as well as – on the other hand – waste statistics and composition distinguished by economic activities, classified according to the European Classification of Economic Activities (NACE rev.2) and data collected under the Waste Statistics Regulation.

The 2018 IO table for Italy was disaggregated into 63 industries (branches) according to the NACE classification. However, owing to the unavailability of the same high-resolution waste arisings data, these industrial sectors were aggregated into 17 branches as described by Table 1.

Table 1 – Industry (branches) classification considered for the analysis (million Euro).

Sector	
(I)	Agriculture forestry and fishing
(II)	Mining and quarrying
(III)	Manufacture of food products, beverages and tobacco products
(IV)	Manufacture of textiles and related products
(V)	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
(VI)	Manufacture of paper and paper.products; printing and reproduction of recorded media
(VII)	Manufacture of coke and refined petroleum products Fabbricazione di coke e prodotti derivanti dalla raffinazione del petrolio
(VIII)	Manufacture of chemical, pharmaceutical, rubber and plastic products
(IX)	Manufacture of other non-metallic mineral products
(X)	Manufacture of basic metals and fabricated metal products
(XI)	Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles and other transport equipment.
(XII)	Manufacture of furniture; jewellery, musical instruments, toys; repair and installation of machinery and equipment
(XIII)	Electricity, gas, steam and air conditioning supply
(XIV)	Water collection, treatment and supply
(XV)	Waste collection, treatment and disposal activities; materials recovery; sewerage management, sanitation and other waste management services
(XVI)	Construction
(XVII)	Services

As for the waste classification, the distinction of 33 different types of waste follows the classification presented in Table 2.

Table 2 – Waste categories for each economy activity (NACE classification, rev 2 – quantities in tonnes)

Category of waste	
1.	Acid, alkaline or saline wastes
2.	Animal and mixed food waste
3.	Animal faeces, urine and manure
4.	Batteries and accumulators wastes
5.	Chemical wastes
6.	Combustion wastes
7.	Common sludges
8.	Discarded equipment (except discarded vehicles and batteries and accumulators waste) (W08 except W081, W0841)
9.	Discarded vehicles
10.	Dredging spoils
11.	Glass wastes
12.	Health care and biological wastes
13.	Household and similar wastes
14.	Industrial effluent sludges
15.	Metal wastes, ferrous
16.	Metal wastes, mixed ferrous and non-ferrous
17.	Metal wastes, non-ferrous
18.	Mineral and solidified wastes (subtotal)
19.	Mineral waste from construction and demolition
20.	Mineral wastes from waste treatment and stabilised wastes
21.	Mixed and undifferentiated materials
22.	Paper and cardboard wastes

23.	Plastic wastes
24.	Rubber wastes
25.	Sludges and liquid wastes from waste treatment
26.	Soils
27.	Sorting residues
28.	Spent solvents
29.	Textile wastes
30.	Used oils
31.	Vegetal wastes
32.	Waste containing PCB
33.	Wood wastes

In the analysis presented in this paper, we have considered a waste treatment sector (Branch XV in Table 1), whose level of activity depends on the amount of waste treated. Furthermore, it is worth noting that the WIO model introduced is a single region model with a domestic technology assumption in which the impact of import and export flows on waste is not considered.

2.3 Methodology

The derivation of the WIO table for Italy and the related statistical analysis are carried out following the approach proposed by Salemdeeb et al. (2016) and the mathematical structure based on the principles of the IOA (Miller and Blair, 2009). This approach has the power – according to Salemdeeb et al (2016, page 1090) "to capture both direct and indirect waste arising across the supply chains", by means of the following equations:

$$V = LY \tag{1}$$

$$L = W(I - A)^{-1} \tag{2}$$

$$L_{direct} = W(I + A) \tag{3}$$

$$L_{indirect} = W[(I - A)^{-1} - (I + A)] \tag{4}$$

in which V represents a vector registering the waste arisings (measured in tons) generated because of final demand represented by the vector V (million Euros) while L is the vector containing the waste arisings associated with the supply chain. In equation (2) W is the coefficient matrix describing waste arisings at each stage per monetary unit of output, A is the matrix of technical coefficients while $(I - A)^{-1}$ is the Leontief inverse coefficient matrix resulting from the Italian 2018 IO table.
It is important noting that the L_{direct} matrix - detailed in 33 categories of waste (on the rows) for each industry – describes waste associated with suppliers directly supplying the industry under consideration. On the other hand, the matrix $L_{indirect}$ with the same level of detail refers to the indirect suppliers, i.e. suppliers that do not directly supply the industry under consideration but are suppliers to the industry's suppliers, described by Salemdeeb et al (2016) as first level indirect suppliers, second-level suppliers, etc.

3. The IO analysis and the Food-Waste data for Italy: provisional results

Based on the L-matrix obtained according to Equation 2, the sector generating the highest waste rate is Construction with 458.3 tonnes of waste per million Euros of final demand. This is followed by the Manufacture of other non-metallic mineral products and Manufacture of basic metals and fabricated metal products. The branches of economic activity that, on the other hand, generate the least amount of waste in total are the services industry - despite the high level of disaggregation - with an amount of 34 tonnes of total waste per million Euro of final demand, the mining and quarrying industry (with 39.6 tonnes of waste per million of final output) and agriculture, forestry and fishing.

Table 3 – Breakdown of total waste into direct and indirect sources: share (% values) per economy activity

Sector	Direct Waste	Indirect Waste
Agriculture forestry and fishing	64.10%	35.90%
Mining and quarrying	89.03%	10.97%
Manufacture of food products, beverages and tobacco products	58.39%	41.61%
Manufacture of textiles and related products	57.17%	42.83%
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	79.67%	20.33%
Manufacture of paper and paper.products; printing and reproduction of recorded media	72.77%	27.23%
Manufacture of coke and refined petroleum products Fabbricazione di coke e prodotti derivanti dalla raffinazione del petrolio	59.88%	40.12%
Manufacture of chemical, pharmaceutical, rubber and plastic products	62.87%	37.13%
Manufacture of other non-metallic mineral products	80.36%	19.64%
Manufacture of basic metals and fabricated metal products	72.07%	27.93%
Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles and other transport equipment.	46.99%	53.01%
Manufacture of furniture; jewellery, musical instruments, toys; repair and installation of machinery and equipment	55.95%	44.05%
Electricity, gas, steam and air conditioning supply	60.09%	39.91%
Water collection, treatment and supply	99.18%	0.82%
Construction	89.63%	10.37%
Services	55.87%	44.13%

It is interesting to observe from the distinction between direct and indirect waste, how there is high heterogeneity between sectors and between different production sectors. With reference to indirect waste, it ranges from an amount close to 1% within the water collection, treatment, and supply industry - although this aggregation needs further and more in-depth understanding - to the highest value recorded for the manufacture of Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles and other transport equipment (53%). Within this range, the trend already emerged for the British economy (Salemdeeb et al., 2016) is partially confirmed for the Italian economy, in which sectors with a longer production chain record higher percentages of indirect waste - this is the case, for example, for services, the manufacture of electronic products, textiles but also foodstuffs - while the generation of indirect waste for the primary industrial sector (mining and quarrying), as well as for construction, is relatively smaller.

4. Further research and Conclusion

The integration of IO analysis with the circular economy concept offers insights for the improvement of waste management practices. Indeed, this analysis framework enables the identification of waste prevention opportunities, the optimisation of material and energy flows, and the assessment of the overall environmental and economic performance of circular economy strategies, as it allows researchers, and thus policy makers, to assess the contribution of each sector to direct and indirect waste generation.
Furthermore, by adopting a systems perspective, IO analysis helps policymakers and practitioners to develop waste management strategies that minimise environmental impacts, promote resource efficiency and contribute to the transition to a circular economy.
The preliminary IO analysis and results proved to be a valuable tool to measure waste issues in Italy and to address the peculiarities of Italian supply chains. By capturing the interconnections between sectors and quantifying waste flows, this approach provides a comprehensive understanding of the waste produced and its management.

Further analysis will involve comparing direct and indirect waste within the same industry and between the various economic activities involved in production processes. In addition, the availability of more detailed data on the waste sector in the national accounts would allow us to delve deeper into resource flows along the different supply chains.

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