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SECTORAL INTERDEPENDENCIES AND WASTE GENERATION IN POLAND (2010–2018): INSIGHTS FROM INPUT-OUTPUT ANALYSIS

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ABSTRACT: The purpose of this study is to investigate the complex interdependencies between economic activities and waste generation within the Polish economy, focusing on identifying the key sectors and observing their changes in sectoral categorisation between 2010 and 2018 (the most current data available). By using Input-Output (IO) tables and analysing five pairs of backward and forward linkages, the research aims to identify the key sectors in the context of waste generation, the changes in sectoral-linkage classifications over the specified period, and the implications of these dynamics for policy-making and strategic planning in the realm of sustainable development. The findings reveal significant insights into the patterns of waste generation across different sectors, highlighting the Mining and Quarrying, Manufacturing, and Energy sectors as the primary contributors. The study also takes into consideration the size of sectors, which allows for the comparison of areas of the economy with different functions and scales. By including this parameter, it was possible to identify the Agriculture, Forestry and Fishing sector, and two sectors from the Manufacturing group as key sectors. Moreover, the study identifies shifts in the waste generation profile of sectors, offering a nuanced understanding of the economy's structural changes in relation to waste generation. By filling an empirical knowledge gap with detailed analysis, this research not only advances the understanding of waste management strategies within Poland but also provides a valuable database for policymakers to develop targeted and effective interventions.

KEYWORDS: input-output table, waste generation, multiplier analysis, backward linkages, forward linkages

Introduction

Every functioning economy is based on a network of local and global dependencies, where sectors producing their goods and services rely on products and supplies from other sectors, as well as on their own production (Alatriste-Contreras, 2015). One of the by-products of production is waste, which refers to any substance or object which the holder disposes of, intends to dispose of, or is required to dispose of pursuant to the provisions of national law in force. This includes materials that are not prime products for which the generator has no further use for his/her own purposes of production, transformation, or consumption (Directive, 2008; OECD, 2015). This covers a wide range of materials, including but not limited to industrial by-products, unwanted household items, and residual substances from manufacturing processes.

Economic development, along with the level and patterns of individual consumption, is the main factor determining the amount of waste generated, with Poland producing 115,039 thousand tons of waste in 2022. The primary sources were the Mining and Quarrying sector (53.3%), Manufacturing (18.6%), and Electricity, Gas, Steam, and Air Conditioning Supply (11.6%). Additionally, the total amount of waste previously landfilled (accumulated) amounts to 1,828,940 thousand tons (Statistics Poland, 2023). The by-products generated in the form of waste, as well as the increasing amount of accumulated waste, have many negative effects on communities and the environment. These effect may include air, soil and water pollution, such as emission of hazardous gases such as green house gases (Gaur et al., 2020; Kumar et al., 2020), depletion of the ozone layer (Morales-Méndez & Silva-Rodríguez, 2018), soil degradation (Krishna & Govil, 2007), toxic effect on crops (Abbas et al., 2015) and water contamination (Dsikowitzky & Schwarzbauer, 2014; Van Wezel et al., 2018).

The objective of this paper is to answer the following questions using Input-Output tables and backward/forward linkages:

- What are the key sectors in the Polish economy in terms of waste generation – understood as those with both forward and backward linkages greater than 1, indicating their strong interconnections with other industries in terms of waste generation dynamics?
- Are there sectors in Poland that have changed their sectoral-linkage classification (weak-oriented; forward/backward-oriented; key sectors) during the period 2010-2018 in relation to the policy variable of waste generation?
- What implications do the backward and forward linkage analyses have for policy-making and strategic planning in the context of sustainable development within the Polish economy?

The results of this study add significantly to the body of knowledge on waste management by offering novel and significant insights. Additionally, by using input-output tables and backward/forward linkages to examine waste generation in Poland, the study fills a knowledge gap. The analysis conducted over the period 2010-2018 offers meaningful observations within the Polish economy and the determination of trends in waste generation across various sectors. It also supports the evaluation of the effectiveness of existing environmental policies and strategies, providing insight into the changes that have occurred in the realm of waste generation. These findings not only advance understanding in this field but also provide a basis for future studies aiming to investigate and tackle waste management issues comprehensively. Furthermore, the paper will enable a better comprehension of the complex connections between sectors of the Polish economy in the context of the waste generation issue. The results can serve as a valuable database for policymakers in Poland to formulate more targeted and effective waste management strategies. The analysis can assist in identifying which areas require an intensification of reduction actions or recycling, contributing to better resource management. Consequently, the findings from this study could inform policy decisions at both a national and international level. This contributes to the development of sustainable strategies focused on efficient waste management and the enhancement of economic resilience, thereby creating a compelling argument for the critical role of this study in shaping both immediate and long-term policy and strategic approaches in waste management and sustainability.

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Literature review

The concept of Input-Output (IO) analysis was introduced by Wassily Leontief in the late 1930s and served as a framework for analysing dependencies between sectors in the economy (Leontief, 1936). Data presented in the interindustry transaction table enables the tracing of product flows from every industrial sector (producer) to other sectors, including the sector itself (consumer). Since then, IO models have attracted significant interest among economists, who employ them for analyses at not only the local level but also on the global scale. Additionally, the scope of these models has been extended to include environmental aspects, integrating tools for assessing the ecological impacts alongside traditional sectoral analyses (Chen & Chen, 2011; Mattila et al., 2013; Sánchez-Chóliz & Duarte, 2005).

From a global perspective, IO models are used in the field of waste generation by many scholars, among other purposes, for analysing the interconnections between sectors and assessing waste management strategies in different economies. These models facilitate a comprehensive understanding of the economic and environmental implications of waste production and disposal. Examining the case of Spain, the authors apply the IO hybrid Life Cycle Assessment model to estimate the quantity of waste generated by both indirect and direct suppliers (Ruiz-Peñalver et al., 2019). In another article, the Structural Decomposition Analysis (SDA) method is used to examine the determinants of waste generation changes in the Australian economy between 2007 and 2014. This approach reveals that final demand is the primary driver of waste output, with the manufacturing sector being the most significant contributor in terms of waste generation (He et al., 2019). The study conducted in South Korea developed an extended waste Input-Output table for industrial hazardous waste (IHW). This led to the identification of the 'Electronic and electrical equipment', 'Chemical', and 'Basic metals' industries as the top contributors to direct IHW generation, accounting for over half of the total amount, whereas domestic consumption was responsible for more than 48% of IHW generation from a demand perspective (Daye et al., 2022). Another example of using IO models is found in an article about the United States, which presents the analysis of three types of waste: hazardous waste, hazardous waste excluding construction waste, and hazardous waste from construction. As a result, chemical and plastic industries are identified as the major producers of hazardous waste. The road construction and chemical sectors are highlighted as areas for further innovation in material utilisation (Meyer et al., 2020). For a more comprehensive and detailed exploration of Input-Output models in the context of waste generation, readers are encouraged to consult the seminal work by Nakamura and Kondo (2009). For critical evaluations of these models' methodologies and applications, the review by Towa et al. (2020) offers essential insights into waste management research.

The continuous development of intersectoral flow frameworks has led to the creation of numerous metrics, such as multipliers, which enable a deeper understanding of the complex connections between the sectors. The indicators discussed in this article will be backward and forward linkages, which can be used not only to reflect gross-output-related processes but also policy goals such as greenhouse gas NOx/SO_2 emissions, water consumption, land disturbances, or energy consumption (Lenzen, 2003; Yousaf, 2015; Li et al., 2023). Within the framework of examining the impact of economic activities on the natural environment, Input Output multipliers play a crucial role by offering a tool for precise analysis of resource flows and emissions. This methodology enables a comprehensive understanding of both direct and indirect environmental impacts arising from sectors' production. Given the scarcity of literature specifically focusing on the application of forward and backward linkages in waste generation contexts, this discussion will instead highlight examples of their implementation in addressing environmental issues. To illustrate the practical applications and outcomes of this approach, let us now examine specific examples of scholarly works that have applied IO multipliers to address ecological issues.

In the study focusing on China, the authors use Structural Decomposition Analysis (SDA) and linkage analysis to identify the key factors and sectors that have impacted production-source CO_2 emissions in China. Results indicate an improvement in emission intensity between 2005 and 2010, aided by input intensity, which contributed to reducing CO_2 emissions, and the identification of nine key sectors (Chang & Lahr, 2016). In another comprehensive study, also conducted for the Chinese economy, researchers used a multi-regional Input-Output model to identify not only key sectors but also key provinces of China. By employing of forward, backward and CO_2 emissions linkages, com-

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bined with both marginal and absolute measures, Hebeim, Shanxim, inner Mongolia, and Shandong were identified as key provinces (Wen & Wang, 2019). The application of forward and backward linkages to data from Spain led to conclusions that the sectors inducing the most emissions from others are the manufacture of food products, wholesale and retail trade, and construction. Simultaneously, sectors like electricity and gas provision, agriculture, and transportation, which are significant for their own final demand, also tend to have high emissions, illustrating a correlation between sectors critical for their output and their environmental impact (Alcántara & Padilla, 2020). A case study conducted for the Greek economy using 2018 data on GHG emissions revealed that sectors such as Electricity, gas, steam, and air conditioning supply, Manufacture of rubber and plastic products and other non-metallic mineral products, and Water supply; sewerage, waste management, and remediation activities were identified as the top three industries with the highest total backward and forward GHG emissions linkages. This indicates that these sectors both influence and are influenced by other industries in terms of GHG emissions within the economy. As a result, any change in production patterns within these industries triggers a domino effect (Tsirimokos, 2023). Linkages analysis has been used in research to examine the role of economic sectors and pathways in water resource consumption and CO_2 emissions, providing a comprehensive characterisation of each sector within China's supply chain. The study highlights which provinces serve as major exporters or importers of products containing substantial amounts of scarce water and CO_2 emissions. Consequently, exporter regions experience significant water stress and strict CO_2 reduction mandates, whereas importer regions may displace their environmental burden onto other areas via supply chain dynamics (Fang & Chen, 2018). Another study focusing on the Beijing-Tianjin-Hebei region in China applied Input-Output models combined with the integrated nexus strength metric and net backward and forward linkages to identify interconnections between embodied water usage and $PM_{2.5}$ emissions within the socio-economic system. By incorporating the integration index (INS), the authors were able to rank the environmental performance of economic sectors and identify key water-$PM_{2.5}$ nexus nodes. The analysis identified 14 sectors with values exceeding the regional average, primarily related to energy, (non-)metal industries, residential services, and agriculture (Gao et al., 2020). The study conducted on Iran's economy identified six key sectors contributing to fossil energy consumption: production and distribution of electricity, crude oil and natural gas extraction, transportation, manufacture of chemicals and chemical products, services, and manufacture of other non-metallic mineral products. Additionally, it suggested an energy management policy aimed at promoting cleaner production practices within these sectors (Faridzad et al., 2020).

While the application of IO multipliers has been extensively discussed from a global perspective, illustrating their effectiveness in various sectors, a specific focus on Poland reveals a gap in the literature, particularly concerning environmental issues. This transition allows us to explore the broader implications of IO multipliers within the Polish economy, providing a comprehensive overview beyond environmental considerations. In their study, Gurgul and Lach (2021) used a linkages-based approach to both identify sectors with a high potential for CO_2 pollution and to develop an innovative variant of sensitivity analysis that allows tracing transactions that cause widespread pollution. Following the examination of research on key sectors, it is worth considering another dimension of the Polish economy presented by the same authors, which centers on the analysis of income per gross output and identification of which countries have remained key sectors in CEE transition economies using World Input Output Data (Gurgul & Lach, 2015, 2018). Using IO multipliers, the study conducted by Loizou et al. (2019) aims to identify industries related to the bioeconomy and assess their potential within the Polish economy. As a result, the sectors have been determined, and linkage coefficients estimated to capture their direct and indirect impacts on the Polish economy. In another study, an alternative method for identifying key sectors was applied based on the normalisation of the Leontief inverse. The results obtained were formally and empirically compared with those from the Classical Multiplier Method and the Hypothetical Extraction Method, using IO tables from 2010 for Poland and Spain (López et al., 2021). Building on the use of 2010 IO tables for economic analysis, this subsequent study applies backwards and forward linkages to compare the structure of production in Poland with those of selected European Union countries, with a focus on identifying key sectors and assessing the strength of inter-industry linkages (Górska, 2015). The Polish economy was also examined alongside selected Central and Eastern European economies to investigate the causal relationship between forward linkages from domestic services to manufacturing and a country's role

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in global value chains. The findings indicate that the Baltic countries and the Czech Republic have enhanced their positions in GVCs through strong financial sector- manufacturing connections, whereas Poland exhibits robust linkages between transportation services and manufacturing (Kordalska & Olczyk, 2021). In the context of strategic economic planning, a study analysing the Polish economy through IO tables for 1995, 2000, and 2004 stands as a valuable resource. The research identifies key sectors by examining their backward and forward linkages, not only highlighting the sectors critical for Poland's economic development but also offering insights into their evolution over the specified period (Olczyk, 2011). For both theoretical and empirical studies concerning the tracing key sectors and IO coefficient in the Polish economy, readers are encouraged to explore the detailed text by Lach (2020).

Methodology

Let's begin our considerations by recalling two IO models – the Leontief model (demand-driven) and the Ghosh model (supply driven), which will serve as the basis for further calculations of forward and backward linkages. Throughout this paper, matrices are represented by bold capitals, vectors by bold lowercases and scalars by italic capitals and lowercases. Moreover, transposition is denoted by a prime, circumflex indicates a diagonal matrix and x^{-1} defines a vector where each element is the inverse of corresponding element in a nonzero vector x.

Following standard notation in IO literature and considering an economy that consists of *n* sectors, the representation of Leontief model is as follows:

$$x = (I - A)^{-1} f = Lf \tag{1}$$

where:
$A = [a_{ij}]_{i,j=1,\dots,n}$ – the $n \times n$ technology coefficient matrix,
I – the $n \times n$ identity matrix,
x – the output vector,
f – the final demand vector,
$(I - B)^{-1} = G = [g_{ij}]_{i,j=1,\dots,n}$ – the Ghosh inverse,
$(I - A)^{-1} = L = [l_{ij}]_{i,j=1,\dots,n}$ – the Leontief inverse.

By transposing vertical view of the above model to a horizontal one, Ghosh model takes the form:

$$x' = v'(I - B)^{-1} = v'G \tag{2}$$

where:
$B = [b_{ij}]_{i,j=1,\dots,n}$ – the $n \times n$ allocation coefficient matrix,
I – the $n \times n$ identity matrix,
x' – the output vector,
v – the value added vector and the matrix,
$(I - B)^{-1} = G = [g_{ij}]_{i,j=1,\dots,n}$ – the Ghosh inverse.

Foundation of the backward and forward linkages

From the economic perspective, the process of production causes two different effects on the rest of the economy's sectors. In the scenario where a given sector, referred to as sector *j*, increases its production, there's a rise in its demand for inputs from sectors that supply what it needs for production, representing a demand-side dynamic. This relationship, known as backward linkage, highlights how sector *j*, by increasing its demand as a buyer, affects the sectors that provide these necessary inputs, essentially connecting it with 'upstream' suppliers. Conversely, when sector *j* increases its output, it leads to more of its products being available to serve as inputs for other sectors' production activities. This results in an enhanced supply from sector *j*, now in the role of a seller, to sectors that incorporate its products into their own production processes. The aspect of supply dynamics is captured in the concept of forward linkage, which describes the connection between sector *j* and the 'downstream' sectors that utilise its output. (Miller & Blair, 2009). Considering the above relationships, backward linkages are calculated using the Leontief model. For this very reason, the Leontief model is applied for its capability to assess the demand for inputs required in the production processes across different sectors. Similarly, the Ghosh model, which is primarily used for calculating forward linkages, serves as a foundation for these calculations and allows for the effective evaluation of the impact of output changes on the entire economy.

The extension of the IO model enables to include a policy-targeted variable, denoted as π^t_i, where in the context of our study, this variable specifically quantifies the amount of waste generated by sector *i* per unit of output from the same sector at period *t.* By denoting the level of waste generation by e^t_i, the policy variable for Leontief model is in the form of:

$$e_t = \hat{\pi}_t L_t f_t \tag{3}$$

where $e_t = [e^t_i, i = 1, ..., n]$. and $\pi^t_i, i = 1, ..., n$. Similarly, this formula can be used for the Ghosh model, in which the variable is defined as:

$$e'_t = v'_t G_t \hat{\pi}_t \tag{4}$$

where $v'_t = [v^t_i, i = 1, ..., n]$.

In this paper, both non-normalized and normalised IO linkages will be presented, as there is no single ideal measure that describes the complex connections between sectors. Each of these linkages provides a unique perspective on the economy under analysis and allows for a better understanding of the dependencies between sectors that occur in the context of waste generation. The combined use of a few types of linkages offers valuable insights into economic structures and their implications for waste production. The overview in Table 1 below presents five pairs of backward and forward linkages: total linkages, hypothetical extraction linkages, and net linkages.

Table 1. Summary of backward and forward linkages

Backward linkage of sector i		**Forward linkage of sector i**	
Name	**Definition**	**Name**	**Definition**
Total backward linkage	$\overline{BACK}^{TOT}_{i,t}(\pi_t) = \sum_{k=1}^{n} \pi^t_k l^t_{ki}$	Total forward linkage	$\overline{FORW}^{TOT}_{i,t}(\pi_t) = \sum_{k=1}^{n} g^t_{ik} \pi^t_k$
Size-adjusted total backward linkage	$BACK^{TOT}_{i,t}(\pi_t) = \frac{\overline{BACK}^{TOT}_{i,t}(\pi_t)}{\pi^t_i}$	Size-adjusted total forward linkage	$FORW^{TOT}_{i,t}(\pi_t) = \frac{\overline{FORW}^{TOT}_{i,t}(\pi_t)}{\pi^t_i}$
Hypothetical extraction (HE) backward linkage	$\overline{BACK}^{CHE}_{i,t}(\pi_t) = \overline{BACK}^{TOT}_{i,t}(\pi_t) \frac{x^t_i}{l^t_{ii}}$	Hypothetical extraction (HE) forward linkage	$\overline{FORW}^{CHE}_{i,t}(\pi_t) = \overline{FORW}^{TOT}_{i,t}(\pi_t) \frac{x^t_i}{g^t_{ii}}$
Size-adjusted HE backward linkage	$BACK^{CHE}_{i,t}(\pi_t) = \frac{BACK^{TOT}_{i,t}(\pi_t)}{l^t_{ii}}$	Size-adjusted HE forward linkage	$FORW^{CHE}_{i,t}(\pi_t) = \frac{FORW^{TOT}_{i,t}(\pi_t)}{g^t_{ii}}$
Net backward linkage	$BACK^{NET}_{i,t}(\pi_t) = BACK^{TOT}_{i,t}(\pi_t) \frac{f^t_i}{x^t_i}$	Net forward linkage	$FORW^{NET}_{i,t}(\pi_t) = FORW^{TOT}_{i,t}(\pi_t) \frac{v^t_i}{x^t_i}$

Source: Lach (2020).

After calculating backward and forward linkages, the next step is the normalisation to unity, which makes them easier to compare across the economy. In doing so, relative-to-average linkage indicators measure the intensity of a sector's interactions with other sectors compared to the average intensity of interactions across all industries. The main goal of the above-described calculations is to classify the economic sectors into one of four categories using Table 2.

Table 2. Sectors' classification based on backward and forward linkages

		Forward Linkages	
		Low (<1)	High (>1)
Backward Linkages	Low (<1)	Weak linkage sectors	Strong forward linkage sectors
	High (>1)	Strong backward linkage sectors	Key sectors

Source: Gurgul and Lach (2015).

Dataset and sector classification

Considering the availability of data, an analysis was conducted for the period from 2010 to 2018. The study employed data sets such as Input-Output tables containing products produced within the country and imported as well as data on waste generation in thousands of tons by individual sectors (OECD, 2021a, 2021b). Data in the IO tables was converted from US dollars (USD) to Polish zloty (PLN) and adjusted for inflation, with all necessary exchange and inflation rates sourced from the OECD database (OECD, 2023a, 2023b). Due to the limited availability of waste generation data for each of the original 45 sectors, they were aggregated into sixteen categories, using a method described in Subsection 4.9.1 of Miller and Blair (2009). The categorisation of sectors into groups can be found in Table 1 as outlined below.

Table 3. Classification of sectors into groups

Category name	**Number of sectors belonging to each category**
Agriculture, forestry and fishing	S01-03
Mining and quarrying	S05-09
Manufacture of food products; beverages and tobacco products	S10-12
Manufacture of textiles, wearing apparel, leather and related products	S13-15
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	S16
Manufacture of paper and paper products; printing and reproduction of recorded media	S17-18
Manufacture of coke and refined petroleum products	S19
Manufacture of chemical, pharmaceutical, rubber and plastic products	S20-22
Manufacture of other non-metallic mineral products	S23
Manufacture of basic metals and fabricated metal products, except machinery and equipment	S24-25
Manufacture of computers, electronic and optical products, electrical equipment, motor vehicles and other transport equipment	S26-30
Manufacture of furniture; jewelry, musical instruments, toys; repair and installation of machinery and equipment	S31-33
Electricity, gas, steam and air conditioning supply	S35
Water collection, treatment and supply; sewerage; remediation activities and other waste management services	S36-39
Construction	S41-43
Other Sectors	S45-98

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The sectors in the above table align with both Statistical classification of economic activities in the European Community (NACE Rev.2) and International Standard Industrial Classification system (ISIC Rev.4), which can be accessed for a comprehensive list of associated sectors and their abbreviations (Eurostat, 2008; United Nations Statistical Division, 2008).

Research outcomes

The results of the calculations are presented in Table 4, which includes a comprehensive summary of all analysed sectors, as detailed in Table 3, along with five pairs of linkages from Table 1, covering the period 2010-2018. The findings were classified into appropriate categories using labels presented in Table 2 for five periods, which were separated by the "|" symbol. In this context, "W" denotes a weak-oriented sector, "S_B" indicates a backward-linkage-oriented sector, "S_F" represents a forward-linkage-oriented sector, and "K" identifies a key sector. For instance, the notation "W | W | S_F | K | K " indicates that the sector under analysis, according to the given pair of multipliers, was categorised as weak-oriented in both 2010 and 2012, became forward-linkage-oriented in 2014, and finally transitioned to a key sector for the years 2016 and 2018.

Analysing total linkage, it is possible to identify sectors such as *Mining and quarrying*, and *Electricity, gas, steam, and air conditioning supply*, which have been recognised as key sectors throughout the entire period analysed. The sector *Manufacture of basic metals and fabricated metal products, except machinery and equipment*, shifted from being categorised as a key sector to being weak oriented since 2014. Meanwhile, *Water collection, treatment and supply; sewerage; remediation activities, and other waste management services* were considered key sectors, with the exception of the years 2012 and 2014, during which they were categorised as forward-linkage oriented sectors. Total backward and forward linkages inform us, respectively, about the economy-wide level of waste generation per unit of final demand and per each unit of gross output of sector . Looking at the total linkage formula it does not consider the size of a given sector. Typically, sectors of large (or small) sizes have a correspondingly large (or small) impact on the economy, which may lead them to be seen as key sectors (Temursho, 2016). This is also the case for the sectors analysed, where e.g., *Mining and quarrying* sector is responsible for generating between 43% to 48% of waste during the analysed period, similar to the *Electricity, gas, steam, and air conditioning supply* sector, which accounts for generating between 18% to 33% of waste.

Considering the size of sectors, the size-adjusted total linkage was calculated, revealing that the sectors previously identified as key according to the total linkage indicator became weak-oriented throughout the entire period analyzed. On the other hand, the *Manufacture of coke and refined petroleum products* sector became a key sector, while both *Agriculture, forestry and fishing* and *Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles, and other transport equipment* were weak-oriented in 2010 and 2012. They then shifted to strong-forward-oriented in 2014 and 2016, and ultimately became key sectors in 2018. The size-adjusted backward linkage measures the indirect waste generated across the economy for each unit of final demand of sector . Meanwhile, the size-adjusted forward linkage refers to the economy-wide level of waste generation per unit of primary inputs of sector *i*.

Another indicator, the hypothetical extraction (HE) linkage, assesses a sector's importance by its total (hypothetical) removal from the Leontief/Ghosh model, which enables to compare the results before and after its elimination. HE backward linkage gives us the information about the overall reduction in waste generation across the entire economy as a result of elimination of sector from a demand-driven perspective, whereas HE forward linkage takes into account a supply-driven approach. Similarly to the total linkage, the size of the sector also matters for the HE linkage. The removal of a large (or small) sector in terms of size from the economy will result in significant (or minor) changes in the amount of waste generated. Consequently, the key sectors are *Mining and Quarrying*, and *Electricity, Gas, Steam, and Air Conditioning Supply*. Additionally, *Construction* sector is an additional key sector, not identified previously. Due to the high aggregation of the *Other Sectors* group, it has been included in the calculations and tables for completeness but is not considered in the analyses because of its wide aggregation. Furthermore, the sector of *Manufacture of basic metals*

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and fabricated metal products, except machinery and equipment, was forward-linkage oriented in the years 2010 and 2014, while in the remaining period, it was a key sector.

Using the previously applied method, we can eliminate the impact of sector's size, which leads to backward and forward size-adjusted hypothetical extraction linkage. It provides the non-normalized HE linkage result per absolute amount of waste generated directly by sector where from the backward perspective, it traces from where do the product are coming from. Simultaneously, the forward perspective is answering the question about the final destination of the products across the economy (Temursho, 2016). Using this indicator, the key sectors include the *Manufacture of coke and refined petroleum products* sector, while the *Agriculture, forestry, and fishing* sector experienced a transition from being weak-oriented to forward-linkage-oriented, becoming a key sector. Furthermore, three sectors (*Manufacture of textiles, wearing apparel, leather, and related products*; *Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles, and other transport equipment*; *Manufacture of furniture; jewellery, musical instruments, toys; repair and installation of machinery and equipment*) demonstrate the trend where they shifted from being weak-oriented (2010-2014) to forward-linkage oriented in (2016, 2018).

The last IO multiplier of interest is net linkage, which, unlike previous indicators, represents the dual aspect of sectoral dependence – on one hand, it considers the dependence of the economy on a given sector, and on the other hand, the dependence of that sector on the entire economy. Looking at values during entire analysed period, only the *Manufacture of coke and refined petroleum products* sector was a key sector. Moreover, *Agriculture, forestry and fishing*; and four manufacturing sectors (*Manufacture of textiles, wearing apparel, leather and related products*; *Manufacture of coke and refined petroleum products*; and *Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles, and other transport equipment)* became key sectors in 2018.

The analysis presented in the paper has provided information about sectors of Polish economy, using five pairs of multipliers, where only one demonstrated the two-sided nature of the analyzed sector and the economic system in the context of waste generation. Different indicators allowed for drawing various conclusions (i.e., classification into respective categories), leading to the question of whether any particular indicator holds more importance. In his work, Gurgul and Lach (2015) points out that the greater the number of linkages confirming that the analyzed sector is a key sector, the more compelling the evidence of that sector's significance in the economic system. Considering this note, the *Manufacture of coke and refined petroleum products* sector was a key sector throughout the entire period analysed based on three indicators, similar to the *Agriculture, forestry and fishing* sector, which was identified as a key sector in 2018, considering the same linkages.

Concluding remarks

The aim of this paper was to analyse sectors of the Polish economy for the period 2010-2018 using environmentally extended Input-Output models, as well as backward and forward linkages. To the best of the author's knowledge, such an analysis, focusing on waste generation problem and the application of IO models, has not yet been conducted for the economic structure of Poland. Therefore, this paper fills a significant gap in the literature, which lacks in-depth discussion in the context of environmental issues. The methods and calculations applied can be used to analyse and understand the complex relationships between sectors and other environmental indicators, such as the amount of greenhouse gases emitted or water consumption. The analysis presented contains original empirical results, which may prove significant for researchers as a basis for further investigation, as well as for policymakers in Poland to support them in making long-term strategic initiatives and waste management decisions.

The conducted study allowed for a comprehensive understanding of the dynamics of changes in individual sectors/group of sectors across five time periods, analysing the issue of waste generation for the Polish economy. It is also important to consider the nature of the analysis, which on one hand demonstrates the one-side relationship of the analysed sectors (e.g., total and HE linkages, along with their size-adjusted counterparts), as well as the two-sided relationship between sectors and economy (net linkages). Furthermore, calculating five pairs of indicators for each of the analysed sectors throughout the entire period enabled a detailed analysis of trends in individual sectors. These changes are particularly visible in sectors such as *Agriculture, Forestry and Fishing*; *Manufacture of Textiles, Wearing Apparel, Leather, and Related Products*; and *Manufacture of Computer, Electronic and Optical Products, Electrical Equipment, Motor Vehicles, and Other Transport Equipment*, which are characterised by significant dynamics of change in analysed periods. While a significant portion of sectors in Poland falls into the weak-oriented category, one may summarise the overall result as identifying the sectors of *Agriculture, forestry, and fishing*, as well as some sectors from the *manufacturing* group, as key sectors in the context of waste generation, according to the most up-to-date data. The article addresses the following research questions formulated at the beginning of the text:

- Key sectors in the Polish economy in terms of waste generation, based on the most recent data and normalised total linkages, include *Agriculture, forestry and fishing*; *Manufacture of coke and refined petroleum products*; and *Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles, and other transport equipment*. However, when considering normalized HE linkages, the key sectors are limited to *Agriculture, forestry and fishing* and *Manufacture of coke and refined petroleum products*.
- There are sectors in Poland that have changed their sectoral-linkage classification over the analyzed period. However, given the large number of sectors and the four transition periods between 2010 and 2018, only those that altered their classification in 2018 compared to 2010 are presented. Based on normalised total linkages, *Agriculture, forestry and fishing* and *Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles, and other transport equipment* shifted from weak-oriented to key sectors, while *Manufacture of textiles, wearing apparel, leather, and related products* moved from weak-oriented to forward-oriented. Regarding normalised HE linkages, *Agriculture, forestry and fishing* transitioned from weak-oriented to a key sector, while M*anufacture of textiles, wearing apparel, leather, and related products; Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles, and other transport equipmen*t; and *Furniture; jewellery, musical instruments, toys; repair and installation of machinery and equipment* moved from weak-oriented to forward-oriented. Meanwhile, the *other sectors* group shifted from forward-oriented to weak-oriented.
- Implications of backward and forward linkages for policy-making and strategic planning include identifying key economic sectors that drive or depend on others, allowing for targeted policies to enhance resource efficiency, minimize waste, and promote sustainable growth. These insights enable policymakers to design sector-specific strategies that strengthen intersectoral cooperation, integrate circular economy principles, and improve environmental sustainability within the Polish economy.

The limitations of the analysis mainly include data availability – both current IO tables for the Polish economy and data on the amount of waste generated by sectors. The study was conducted over the period 2010-2018, biennially, as this ensures the availability of both IO tables and data on waste generation. This biennial approach can potentially lead to the omission of annual variations and nuances, smoothing over year-to-year changes in economic activity and waste generation patterns. Furthermore, an additional limitation is the aggregation of data related to the amount of waste generated by individual sectors, hence the analysis covered sixteen sectors/group of sectors. The availability of more data would enhance the accuracy of the research and allow for, among other things, the identification of a specific sector within the group of aggregated sectors that is a key sector concerning waste generation problem. Also, by expanding the dataset to include more granular sector-level data could sharpen the study's findings, enabling more precise policy recommendations.

The direction of future research could focus on a comparative analysis of the results obtained for Poland's economy with those achieved for other countries. On one hand, comparing the research to economies with dynamics similar to Poland's will allow for a critical analysis of the economic structure and will reveal unique patterns hidden in the data. This approach could also foster understanding of how Poland's specific economic policies and industry compositions compare to those of similar nations, shedding light on potential areas for policy refinement or economic innovation. On the other hand, comparing the results to countries that have already implemented innovative ways to minimise waste generation (e.g., through energy transformation) will provide valuable insights for those who are addressing environmental issues, not only policymakers but also investors. Such comparisons might highlight successful strategies and technologies that could be adapted or adopted by Poland to enhance its waste management and sustainability efforts. Given the dynamically developing econo-

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mies and technological innovations, mixed with requirements such as those of the European Union, it will be important to conduct a refresh analysis once current data becomes available. This will provide us with a picture of the current situation and the condition of the economy and will allow for an evaluation of the actions taken. Moreover, it will enable stakeholders to align their strategies with the latest environmental standards and economic practices, ensuring that efforts to reduce waste generation are both effective and sustainable.

Table 4. Classification of sectors based on five pairs of backward and forward linkages for period 2010-2018 with biennial intervals

Sector name	Total linkage 2010 | 2012 | 2014 | 2016 | 2018	Size-adjusted total linkage 2010 | 2012 | 2014 | 2016 | 2018	HE linkage 2010 | 2012 | 2014 | 2016 | 2018	Size-adjusted HE linkage 2010 | 2012 | 2014 | 2016 | 2018	Net linkage 2010 | 2012 | 2014 | 2016 | 2018
Agriculture, forestry and fishing	W | W | W | W | W	W | W | S_F | S_F | K	W | W | W | W | W	W | W | S_F | S_F | K	S_F | S_F | S_F | S_F | K
Mining and quarrying	K | K | K | K | K	W | W | W | W | W	K | K | K | K | K	W | W | W | W | W	W | W | W | W | W
Manufacture of food products; beverages and tobacco products	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W
Manufacture of textiles, wearing apparel, leather and related products	W | W | W | W | W	W | W | W | S_F | S_F	W | W | W | W | W	W | W | W | S_F | S_F	S_F | S_F | W | S_F | K
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W
Manufacture of paper and paper products; printing and reproduction of recorded media	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W
Manufacture of coke and refined petroleum products	S_B | S_B | S_B | S_B | S_B	K | K | K | K | K	S_B | S_B | S_B | S_B | S_B	K | K | K | K | K	K | K | K | K | K
Manufacture of chemical, pharmaceutical, rubber and plastic products	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W
Manufacture of other non-metallic mineral products	W | S_B | S_B | S_B | W	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W
Manufacture of basic metals and fabricated metal products, except machinery and equipment	K | K | W | W | W	W | W | W | W | W	S_F | K | S_F | K | K	W | W | W | W | W	W | W | W | W | W
Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles and other transport equipment	W | W | W | W | W	W | W | S_F | S_F | K	W | W | W | W | W	W | W | W | S_F | S_F	W | W | S_F | K | K
Manufacture of furniture; jewellery, musical instruments, toys; repair and installation of machinery and equipment	W | W | W | W | W	W | W | W | S_F | W	W | W | W | W | W	W | W | W | S_F | S_F	W | S_F | S_F | S_F | S_F
Electricity, gas, steam and air conditioning supply	K | K | K | K | K	W | W | W | W | W	K | K | K | K | K	W | W | W | W | W	W | W | W | W | W
Water collection, treatment and supply; sewerage; remediation activities and other waste management services	K | S_F | S_F | K | K	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W	W | W | W | W | W
Construction	W | W | W | W | W	W | W | W | W | W	K | K | K | K | K	W | W | W | W | W	W | W | W | W | W
Other Sectors	W | W | W | W | W	S_F | S_F | S_F | S_F | S_F	K | K | K | K | K	S_F | W | W | S_F | W	K | S_F | S_F | S_F | S_F

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GENEROWANIE ODPADÓW W POLSCE (2010-2018): ANALIZA SEKTORÓW KLUCZOWYCH PRZY UŻYCIU MNOŻNIKÓW PRZEPŁYWÓW MIĘDZYGAŁĘZIOWYCH

STRESZCZENIE: Celem artykułu jest zbadanie współzależności między sektorami gospodarczymi a generowaniem odpadów w polskiej gospodarce, ze szczególnym uwzględnieniem identyfikacji sektorów kluczowych oraz obserwacji zmian w ich kategoryzacji sektorowej między 2010 a 2018 rokiem. Poprzez wykorzystanie tabel przepływów międzygałęziowych oraz analizę pięciu par powiązań wstecznych i wyprzedzających, badanie ma na celu zidentyfikowanie kluczowych sektorów w kontekście generowania odpadów, zmian w klasyfikacjach powiązań sektorowych w określonym okresie oraz implikacje tych dynamik dla tworzenia polityki i planowania strategicznego w obszarze zrównoważonego rozwoju. Wyniki pokazują znaczące wnioski dotyczące wzorców generowania odpadów w różnych sektorach, wyróżniając sektory *Górnictwo i Wydobycie, Przetwórstwo Przemysłowe* oraz *Energetykę* jako główne źródła w kontekście generowania odpadów. Badanie uwzględnia również wielkość sektorów, co umożliwia porównanie obszarów gospodarki o różnych funkcjach i skalach. Dzięki uwzględnieniu tego parametru możliwe było zidentyfikowanie sektora *Rolnictwo, Leśnictwo i Rybołówstwo* oraz dwóch sektorów z grupy *Przetwórstwa Przemysłowego* jako kluczowych sektorów. Ponadto, badanie wskazuje zmiany w profilu generowania odpadów przez sektory, oferując dogłębne zrozumienie zmian strukturalnych gospodarki w relacji do generowania odpadów. Poprzez wypełnienie luki w empirycznej wiedzy za pomocą szczegółowej analizy, badanie nie tylko poszerza zrozumienie strategii zarządzania odpadami w Polsce, ale również dostarcza cenną bazę danych dla decydentów politycznych, co pozwala opracować celowane i skuteczne interwencje w odpowiednich sektorach gospodarki.

SŁOWA KLUCZOWE: tablica przepływów międzysektorowych, generowanie odpadów, analiza mnożnikowa, powiązania wsteczne, powiązania wyprzedzające

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