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Incineration, Urbanization, and Municipal Solid Waste in the World-System

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Abstract

Incineration, or waste-to-energy, is a widespread means of greenwashing municipal solid waste collection worldwide. This paper looks at incineration and the trade of bottom ash to discuss how urbanization in one country pressures urban expansion elsewhere in the modern world-system. Incineration is a coping mechanism for excess waste produced by cities under capitalism. It generates energy, reduces the volume of waste, and creates ash that can be used in cement production. However, it is far from sustainable, as it facilitates expansion-oriented growth. Using UN Comtrade data, we find that incineration is a material and metabolic process that promotes global urbanization in the following ways: 1.) Corporations producing and selling incineration are part of a transnational growth machine that fuels the treadmill of production. 2.) North-North, North-South, and South-South relationships encourage incineration as a means of ecological modernization. 3.) These relationships have both hierarchical and polycentric dimensions—allowing us to create a typology for understanding such processes within the modern world-system.

Keywords: Incineration, Cities, Urbanization, Waste, Bottom Ash

With over half of the world's population living in urban regions, there is no doubt that globalization has an urban dimension. Since the 1970s, a vast literature on globalization and the world-economy has been produced (Wallerstein [1974] 2011b, [1989] 2011c). Included is work on global cities and the world city network. At the same time, there is growing literature on the relationship between the world-economy and the environment (Sassen 2001; Taylor et al. 2002). However, this literature typically operates separately from the scholarship on cities and urban nature (Heynen, Kaika, and Swyngedouw 2006). This paper seeks to connect such literature via a world-systems perspective to understand better the relationship between waste and urbanization within a global context.

In particular, we look at the global trade of incinerated municipal solid waste (MSW). Incineration has been a coping mechanism for the glut of waste cities produce under capitalism. Our research focuses on the leftovers of incineration: bottom ash. The reason for this is three-fold. First, incineration has become a popular means of greenwashing waste collection worldwide. Notably, the waste management sector prefers to call it waste-to-energy (WtE) or energy-from-waste (EfW), as well as refuse-derived fuel (SDF) or solid-recovered fuel (SRF), to label it sustainable (Malinauskaite et al. 2017). As Lucier and Gareau (2015) argue, despite the passage of national and international regulations addressing waste, the export of such materials has not declined. Instead, the trade of waste has rapidly expanded around the world. This paper looks at how this expansion is linked to other political-economic processes in the world-system.

Second, our focus distinguishes this paper from work examining the extensive global trade of plastic, e-waste, and scrap (Bai and Givens 2021; Pacini et al. 2021; Petridis, Petridis, and Stiakakis 2020; Theis 2021; Wang et al. 2020). This literature primarily emphasizes North-South ecologically uneven exchange. In turn, we argue that South-South relationships must be considered, as cities in newly industrialized countries have become prominent fixtures of the world-economy. Examining material flows in and out of such cities provides insight into how growth-oriented capitalism copes with the problem of waste.

Third, an emphasis on incinerated municipal waste allows us to explore urbanization. Despite UN Comtrade tracking incinerator ash, it is under-examined by critical social scientists. Urbanization involves several metabolic processes. Incineration generates energy for growing cities and addresses hazards associated with refuse. In addition, energy generation for an electrical grid can be used to fuel cement kilns. Conveniently, it would seem, incinerator ash can be used to produce asphalt, cement, and concrete (Lam et al. 2010; Villar, Arribas, and Parrondo 2012).[1] This has become particularly important as the market for sand has become more competitive (Lamb, Marschke, and Rigg 2019). Correspondingly, multinational corporations promote WtE as a solution to multiple urban problems. Fu (2022) argues that contemporary MSW practices fuel urban growth machines and lubricate production's global treadmill (also see: Schnaiberg 1980;

[1] Fly ash from coal power plants can be used as well. Why fly ash has been explored for use in cement and concrete since the 1980s, the use of incinerator ash is a more recent phenomenon (Ferreira, Ribeiro, and Ottosen 2003; Lam et al. 2010).

Logan and Molotch 1987). Expanding on this literature, we add a discussion as to how incineration is a material and metabolic process that promotes global urbanization.

Sustainability, or going green, has become a fixture of local, national, and international policy debates. While international agreements such as the Basel Convention (1989) regulated the movement of waste materials, it certainly did not stop it. Since the 1990s, waste flows from the global North to the global South have increased alongside consumption (Gregson and Crang 2015). We have also seen East-South, and South-South relationships evolve as newly industrialized countries address their growing MSW problems. This includes trading waste or selling waste management technologies. Savini (2019) has argued that this is not just about making waste disappear. Following the ideology of ecological modernization, there are global pressures for a circular economy. This is the idea that the states and markets can modernize to reduce environmental harm. However, this ultimately supports capital accumulation. In other words, sustainability is not the primary goal. As such, scholars argue that recycling is not sustainable (Weinberg, Pellow, and Schnaiberg 2000).

Multinational corporations collect MSW for profit and can generate additional value by turning it into fuel. In addition to energy, the ash can be used in asphalt, cement, and concrete production. Therefore, the distinction between logistics as supply chain management and waste management is a matter of commodification. In turn, framing waste management as logistics is essential given the nature of capitalism—such a framing re-focuses practices such as reuse, recycling, or incineration as value-generating activities. This framing reveals the connection between MSW and capital accumulation. In the case of WtE, urban growth is central. Expansion produces more trash for incineration, but it increases the energy demand. Thus, we need to consider waste as part of global value chains within a capitalist system (Gereffi and Kaplinsky 2001).

This paper examines the material impact of MSW incineration within the world-system. Using UN Comtrade data, we create a typology that situates pressures to urbanize within a global context. Put another way, we view MSW management as part of a larger whole. As a social and material process, urbanization and waste play a significant role in structuring and organizing the world-economy. Looking at trash and refuse involves what Bunker (2003) has called the materio-spatial configurations that influence global economic functions. The trade of incinerator ash as a material is tied to several urban processes within the more extensive system. Put another way, MSW management has an active role in structuring and organizing cities in the world-economy. We argue that this process is more than wealthy cities and nations exporting waste. Instead, the movement of ash is a growing part of how contemporary cities operate with the world-system.

Literature Review

Robinson (2011) argues urbanists often ignore a comprehensive or global comparative approach. Certainly, South-South relationships are not without the North's interventions (Abdenur and Fonseca 2013). More powerful countries and cities influence less wealthy countries and cities in various ways (Bel et al. 2010; McCann 2011). However, we need to remember that agency or agencies exist. The complex flow of people, services, and resources within the cities of newly industrialized countries is, on the one hand, a topic of significant academic interest. Yet, flows between semi-peripheral and peripheral cities, or South-South or East-South relationships, are often under-examined (Bjerkli 2013; see: Horen 2004; Lawhon 2013). Put simply, cities in the global South, like all cities, look externally for solutions to urban problems.

The world-systems approach sees the world-economy as a singular unit of analysis characterized by an axial division of labor, whereby the world is divided into core, semi-peripheral, and peripheral countries (Wallerstein [1974] 2011b, [1989] 2011c). Other research notes that this system of states also relies on natural resource exploitation (Jorgenson 2003; Bunker 2005; Moore 2015). Importantly, states are not the only actors or entities that shape the accumulation process. Cities function as command centers or nodes within the world-economy (Friedmann 1986; Sassen 2001). Unsurprisingly, the world-system has a hierarchy of states and urban centers. Indeed, cities in the global North—often with headquarters of transnational corporations—yield significant influence through their global social and financial networks (Kentor, Sobek, and Timberlake 2011). Cities in the North rely on those in the South for trade, the externalization of environmental risks, and resources.

Undoubtedly, cities outside Europe, Japan, and North America have global political and economic influence. Buenos Aires, Dubai, Istanbul, Jakarta, Johannesburg, Lagos, Mumbai, São Paulo, and Shanghai are just a few cities that have seen significant growth in GDP, population, and waste production in recent years. Going beyond comparative approaches in global urban analyses, we holistically examine South-South and other uneven relations within the world-system. This allows us to examine nuanced relationships and structures within the whole system.

Cities are a manifestation of global processes such as culture and migration (Timberlake 1985; Clark 1998). Global cities such as London, Tokyo, and New York look the way they do because of their connections to other cities—through migration, trade, and other social, economic, and political exchanges (Sassen 2001). There is also a material and environmental dimension. Given the role of cities, they consume resources from well beyond their borders and redistribute pollution and waste across the globe—often producing environmental injustices (Alberti et al. 2003; White 2007; Li et al. 2010). Cities are linked to others via consumption and pollution. A city’s ecological or environmental footprint approximates its use of resources translated into hypothetical global hectares (Rees 1992; Wackernagel and Rees 1998). However, it is arguable that 1.) these footprints have grown to a point where this model’s usefulness is reduced; and 2.) these footprints overlap. Thus, a singular footprint provides a limited view. In turn, it is helpful to refocus our attention and examine their material relationships. Drawing on lessons from world-systems research, we argue that these connections between cities can help us understand how they contribute to environmental harm through urbanization and MSW generation.

Logistically speaking, cities developed shipbuilding, rail, and road infrastructure, allowing national economies to expand and diversify (Bunker and Ciccantell 2003; Ciccantell and Smith 2009). These cities were connected to those within domestic markets and global networks as well. In turn, King (1990) has used the term “world urban system” to describe the globally interconnected system of cities (e.g., ports) over the past several centuries. Knox and Taylor (1995) described this as "world cities in a world-system." Indeed, these networks are structured, and some cities have a more significant influence (Taylor et al. 2002). Much like nation-states, urban centers within the world-system cannot be understood without looking at the global context. Perhaps the best way to discuss the relationship between cities is that they are mutually interdependent. Some port cities are significant nodes within the world-economy despite not being command centers (Jacobs, Ducruet, and De Langen 2010). Arrighi (1994: 133) points out that the historical rise of Italian and Dutch cities in the world-economy was not merely the result of favorable geography and history. Instead, it was the "unintentional effect of the actions of a multiplicity of agencies." Today, it is clear that cities outside of Europe and North America increasingly influence those in lesser developed countries (Mahutga et al. 2010; Fu 2016). Newly industrialized countries and cities increasingly have integral or core-like functions in producing goods and services. As such, Frey's (2015) conceptualization of centrality within the world-system, which allows the core to underdevelop or shift "anti-wealth" to the periphery, is useful in understanding such networks (also see: Frey 1998, 2003).

This network is like a constellation. In the same way, stars in a constellation connect points that produce a contour or shape, a city within a more extensive city system reveals particular structures within the world-economy. This notion of a constellation of cities—a network with a specific form or shape is valuable here. While others have used the term "constellation" in both an American and global context, we emphasize how cities physically shape each other and urbanization around the globe. Wallerstein (2011c: 33) has discussed the importance of examining the "constellation of positions" within the world-economy. Dilworth (2011: 2) once described cities in California, Texas, and Arizona as a "constellation of cities that came to be known as the Sun Belt." The key is that these connections are relational. As Andre Gunder Frank (1969: 6) notes, a "whole chain of constellations of metropoles and satellites" connects the cities within the world-system. The emphasis is that a chain of relationships, or a series of positions, ultimately produces this ecological footprint.

Urbanization under capitalism is a technical strategy to accelerate accumulation, as such connections between countries and cities are materio-spatial relationships. Tactics include extracting natural resources, producing goods, or financial technologies facilitating circuit switching (Aalbers 2020). In this sense, cities are configured to be machines that enable growth. Cities, after all, have been called growth machines. Molotch's (1976) conceptualization of urban growth machines critiqued pro-capitalist urban policy and real estate development. Importantly, many of those practices are now global. Rent-seeking behavior currently operates worldwide, with ecological costs and an increased risk of disaster (Balaban and Fu 2014).

These threats, such as too much waste, affect urban livelihoods and accumulation. As Schnaiberg (1980) argued, extracting finite resources at ever-increasing speeds also meant producing more waste. The management and trade of MSW is a logistical problem that must be addressed for the system to function. Waste management, therefore, cannot be disassociated from other managerial practices that seek to increase the efficiency of the treadmill and growth machines. Over the past few decades, we have seen a dramatic expansion of logistics service providers that play an integral role in supply chain management. Such firms have contracts with private and public entities to handle logistical services such as warehouses and delivery. Many also offer reverse logistics, which involves returning material to the producer or disposal. Therefore, waste management is an example of global supply chain management.

Importantly, MSW management, in many cities, is a monopoly or oligopoly (Biggar 2000). Companies based in cities, like at the national level, require expansion to other geographies to increase their profit margins. These city-level companies compete and collaborate in urban constellations and facilitate (urban) economic growth. This can mean reliance on traditional transportation or infrastructure networks within a region and internationalization. This constellation of cities also represents distribution networks of commodities and a means of shifting the risk associated with waste. Logistical or waste services providers, in turn, allow the urban growth machine to speed up and lubricate the treadmill of production.

Undoubtedly, commodity chains play a significant role in generating waste within the world-system. Cities have many functions and connections within the world-economy, contributing to commodity or value chains. Hopkins and Wallerstein (1986) notably discuss the labor, production, trade, and capital network that shapes commodities (also see: Gereffi and Korzeniewicz 1994). Similarly, Bair (2005) has argued commodity chain research needs to look at the broad contemporary political-economic context that shapes them. Here, we contend the literature needs to consider the materiality of such forces. Notably, the efficiency of capital accumulation relies on production, distribution and consumption, and the handling of waste (Hesse and Rodrigue 2004; Hesse 2008). As such, output within the world-system cannot be understood apart from waste.

Methods

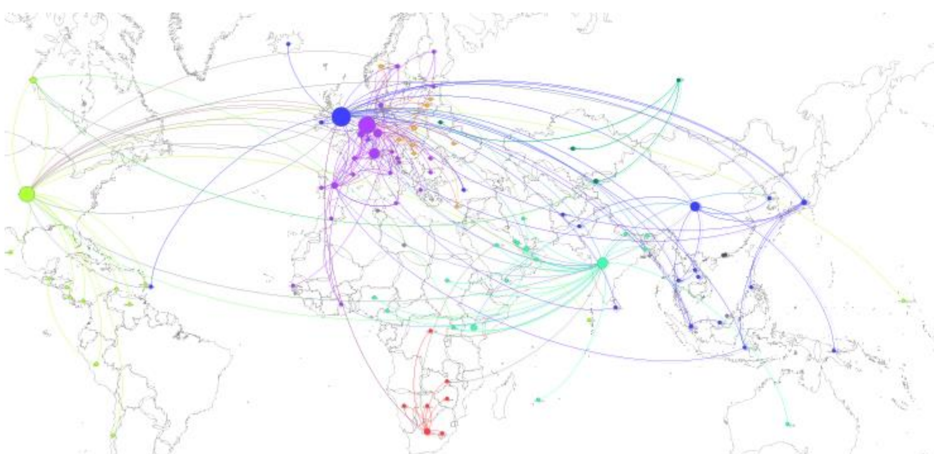
This paper adopts a mixed-methods approach to analyze the relationship between waste and urbanization. As waste management is fundamentally a form of logistics, we conducted a network analysis of UN Comtrade data on incinerator ash. While urbanization is a focus of this paper, we were unable to directly examine city-city flows due to data availability. However, traded ash is designated by Comtrade as a byproduct of municipal solid waste incineration. Moreover, as cities have larger populations, most of the ash would be a byproduct of urban waste generation.

World Bank's (2019) database on the MSW output of 242 cities in 85 countries, which have the related UN Comtrade data, supports this point. The database illustrates a moderate, positive, and significant non-parametric correlation between the MSW output by tones per the inhabitants of the cities covered in the database and the eigencentrality of their countries in the global MSW trade networks (.353, $p<.001$, N: 86). Another indicator we can use is the MSW output per capita at the country level. The nonparametric correlation value between this indicator and the eigencentrality value of these countries is 0.574 ($p<.000$, N: 86). Since this database does not cover most of the individual cities and most of the MSW is produced in cities, the second correlation values is possibly more reliable. Thus, albeit with the necessary caution, we can argue that the more MSW a country's cities produce, the more connected that country is to the global trade networks.

In addition to quantitative data, we reviewed the news media, government, and corporate press releases for local incinerator construction and ash trade developments. Our goal is to present a world-systemic typology of global trade networks of waste as a material input for urbanization. This typology emphasizes the commodification of waste in the form of incineration. Accordingly, we limit the scope of the inquiry to the magnitudes of trade and output.

Following the work of Pacini and colleagues (2021) on plastic scrap, we looked at imports and exports of materials coded by Comtrade. Specifically, we looked at 262110 - Slag and ash; ash and residues from the incineration of municipal waste between 2016 and 2020. Data from Comtrade was entered into Gephi 0.9.2. to find significant hubs of ash trade. We found 100 countries serving as nodes trading in ash in this period. Figure 1 was generated using the Geo Layout algorithm to illustrate flows around the world geographically. Figures 2–5 were generated using the NoOverlap algorithm, partitioning nodes, and color-coded by modularity class. We also found 214 pairs of trading partners that served as edges. Edges between nodes were weighted with the volume (kg) of ash traded. The edges in each figure were not weighted in the figures for readability purposes. The color of the edges between countries in two different clusters will represent the higher-volume trading partner.

Figure 1: Map of Global Incinerator Ash Trade



Source: UN Comtrade (2016-2020). Imports and Exports of 262110 - Slag and ash; ash and residues from the incineration of municipal waste. Visualization generated by Gephi 0.9.2.

In turn, we looked at reported exports and imports when creating edges between nodes over this five-year window for a macro-level view of the global ash trade. Following data entry, we used Gephi 0.9.2. to generate measures of centrality and modularity. It should be noted that declared exports and imports rarely matched. Another point is that not all ash comes from WtE plants. In addition to typical reporting errors, incinerator and fly ash from coal plants are often treated as waste products depending on the context. For instance, South Korea has expressed concern regarding poorly regulated imports of Japanese ash (Chung 2011). Waste is not included in our calculation. There is also cargo loss. Indian ships carrying ash have sunk in Bangladesh (Acharya 2020). Global shipping, especially by sea, is prone to cargo loss.

Looking at Eigenvector centrality, European countries play an integral role within global trade networks of incinerator ash. These countries in the global North are well connected to each other and other significant traders around the world. As Eigenvector measures influence, it is not surprising that countries in the North rank highly. However, major semi-peripheral countries such as India, China, and South Africa have a high betweenness centrality. In other words, they are significant nodes in the global network. It is perhaps important to note that Brazil and Russia, despite their geopolitical influence, do not appear to be very involved in the trade of incinerator ash.

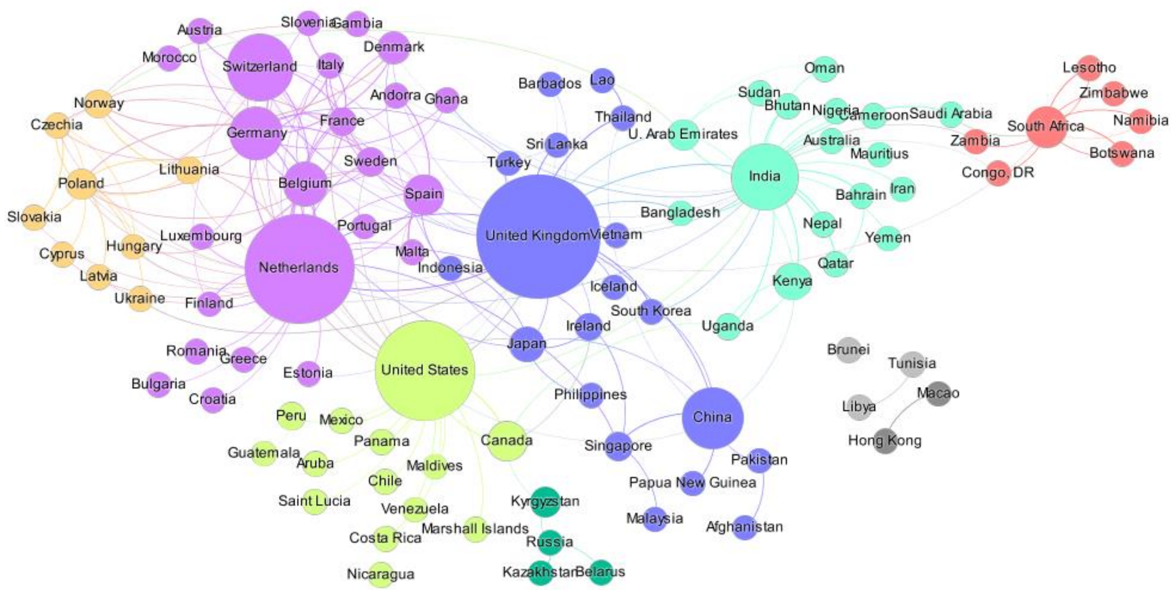
Table 1: Top 10 Countries by Measures of Centrality

	Betweenness		Degree		Eigenvector
United Kingdom	0.159266	**Netherlands**	36	**France**	1
Netherlands	0.136615	**India**	28	**Germany**	0.966929
United States	0.12608	**United Kingdom**	27	**Spain**	0.902738
Switzerland	0.06764	**United States**	25	**Poland**	0.863308
India	0.066793	**Germany**	22	**Netherlands**	0.862592
China	0.057636	**Belgium**	17	**Belgium**	0.849507
Germany	0.044546	**Spain**	16	**Switzerland**	0.747267
Belgium	0.030209	**Switzerland**	16	**Italy**	0.684611
South Africa	0.025563	**Poland**	15	**Hungary**	0.638449
Spain	0.024913	**France**	12	**Luxembourg**	0.507413

Source: UN Comtrade (2016–2020). Imports and Exports of 262110 - Slag and ash; ash and residues from the incineration of municipal waste. Measures generated by Gephi 0.9.2.

Regarding modularity, Gephi generated nine groups, of which there are six significant clusters (See Table 2, Figures 3–5). The older and newer members of the European Union make two respective clusters (Figure 3), while the United Kingdom and China are at the center of a single group (Figure 5). The Americas account for another, while India and South Africa are central to the last two significant global clusters (Figure 4). While Russia and former Soviet states consist of a network, it is not significantly engaged in international trade. Two other small, isolated groups emerged in North Africa and Asia.

Figure 2: Clusters by Modularity Class



Source: UN Comtrade (2016–2020). Imports and Exports of 262110 - Slag and ash; ash and residues from the incineration of municipal waste. Visualization generated by Gephi 0.9.2.

One factor that makes these clusters look intuitively valid is that most networks comprise countries in the same region due to logistical concerns. Nonetheless, proximity is not the sole factor that seems to determine the scope of trade. Newer and older members of the European Union are in different clusters. While the United Kingdom and China are trading ash in their group, these countries are not in the same region. This means that waste logistics is essential not only regionally but globally. Another finding is the emergence of India and South Africa at the center of two different clusters. Correspondingly, there are crucial South-South relationships in addition to those centered around the global North.

These networks of ash trade allow us to examine large-scale patterns within the world-economy. Notably, they illustrate potential urban constellations. We followed our network analysis by looking at the World Bank's (2019) "What a Waste Global Database" to solicit municipal solid waste data. We coupled this data with the clusters based on modularity. Specifically, we looked at the weighted degree of ash traded in relation to MSW generated per capita. This allows us to see how the cities, as the producers and traders of urban waste, are connected in sub-global economic networks. Put another way, the data illustrates specific patterns of treatment of urban waste that provide insight into the operation of the global urban political economy.

Table 2: Typology of Relationships

	Hierarchical	Polycentric
North-North	1. The Netherlands	2. Poland
South-South	3. India	4. South Africa
North-South	5. United States	6. United Kingdom

Corresponding, we created a typology explaining how waste, specifically incinerator ash trade, facilitates urbanization (see: Table 2). The columns indicate the trade networks, which we call "hierarchical" here, where a particular country dominates. These countries generally produce more MSW per capita than others in their network. Alternatively, the "polycentric" column points to a more dispersed network where a few countries have a significant presence. However, we are still noting the most central state within that cluster. The rows of the table illustrate the regional scope of these trade networks.

Despite the imperfect nature of the North-South binary, we argue that the six types of relationships depicted in our typology capture both the complexity and nuance of interstate trade. For the sake of simplicity, we used the World Bank's income groups to define the Global South and the Global North. According to the World Bank classification, countries with a GNI per capita higher than $13,846 are "high-income economies", which we treat here as "the global North" and others as "the global South" (See Table 3).[2]

Table 3 Composition of Clusters

Regional Orientation[3]	Cluster Number	Non-High-Income Economies	High-Income Economies	Share of the High-Income Economies	Share of the Non-High-Income Economies
North-North	1	4	20	**83%**	17%
North-North	2	1	8	**89%**	11%
South-South	3	12	5	29%	**71%**
South-South	4	7	0	0%	**100%**
North-South	5	8	5	**38%**	**62%**
North-South	6	12	7	**37%**	**63%**

[2] Even though we used the GNI-based World Bank (2023) classification to set a monetary threshold, we used the GDP per capita data rather than GNI below for two reasons. First, the GNI per capita database for 2021 lacked values for seven countries in the UN Comtrade database, while GDP per capita database for the same year lacks data only for one country (Venezuela). Second, all countries available in both databases fall in the same income categories, so the GDP per capita database is reliable for the taxonomy we use to define the Global North and the Global South for all countries in the database but for those six countries.

[3] This classification is based on: World Bank. 2022. "GNI per Capita, Atlas method (current US$)." Retrieved September 2, 2023. (https://data.worldbank.org/indicator/NY.GNP.PCAP.CD) and World Bank. 2022. "GDP per Capita (current US$)." Retrieved September 2, 2023. (https://data.worldbank.org/indicator/NY.GDP.PCAP.CD).

Most of the countries in these clusters fit our North-South classification well. As the table above illustrates, the non-high-income economies in the North-North clusters account for a small minority of the total cases, while the opposite is true for the South-South clusters.[4] In the two North-South clusters, the ratio of the non-high-income economies to the total number of cases matches almost precisely the global ratio, which is 64 percent. Moreover, cities in rapidly developing countries such as India and South Africa reflect their centrality within the world-system, despite the countries' overall economic development (see: Frey 2015).

Another element is the significance of the trade volume within these clusters for their leading countries. As the tables above illustrate, on the one hand, India and the Netherlands are not only the best-connected members of their group, but also these countries have the highest trade volume by significant margins. Thus, we call their relationship hierarchical. On the other hand, the United Kingdom and South Africa's major trade partners—in terms of volume—are either closer in trade volume or not located within their cluster. In turn, these groupings illustrate a less hierarchical and more polycentric network.

Urban Constellations

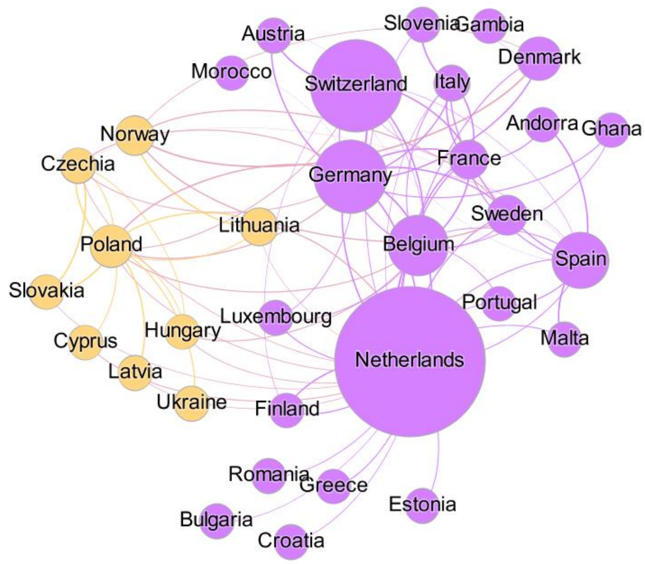
North-North

Countries in the North-North network (Clusters 1 and 2) trade high volumes of incinerating ash with each other (See Figure 3). They account for two clusters generally representing Western and Eastern Europe or earlier and later EU ascension members. Highly connected countries in Cluster 1 are generally more affluent, highly urbanized, and would be considered part of the core of the world-system. They also produce higher outputs of municipal solid waste per capita than those in the global South. The relationship between these two clusters is marked by the need for core nations and cities within their region(s) to address energy and raw material demands.

Here we see North-North incineration as a coping mechanism for energy demands, the need to deal with MSW, and the demand for raw materials. In this group, the Netherlands stands out as a significant node in the network and is deeply involved in incinerator ash trade globally. The Netherlands and several other Western European countries no longer use landfills. In turn, incineration has long played a significant role in waste management. For example, the City of Amsterdam established Afval Energie Bedrijf (AEB) as a WtE service provider in the 1990s. Paris's Saint-Ouen WtE plant also began operation in the same decade. The expansion of incineration since the 1990s was enhanced by national and European Union emissions standards passed at this time that covered waste treatment. This includes Germany, which shifted from landfills to relying primarily on recycling and incineration (BMUV 2001; Ittershagen 2008).

[4] Cluster 3 has a higher number of high-income countries than Cluster 4. Except for Australia, the others are the following hydrocarbon-rich Gulf countries: Bahrain, Oman, Qatar, Saudi Arabia, and United Arap Emirates.

Figure 3: North-North Clusters



Source: UN Comtrade (2016–2020). Imports and Exports of 262110 - Slag and ash; ash and residues from the incineration of municipal waste. Visualization generated by Gephi 0.9.2.

Not coincidentally, the European Union does not label appropriately treated bottom ash as hazardous material. This assumes proper handling of heavy metals and appropriate recycling (Van Gerven et al. 2005). Ireland, for example, sends its ash to the Netherlands to be processed—removing valuable metals and preparing the material for use in construction projects (Kelly 2018). Notable treatment plants include Heros Sluiskil near Terneuzen, an important port city. Of note, the Netherlands has fewer WtE plants than France or Germany, yet it trades a high volume of ash because of this technical dimension. In turn, the trade of ash is influenced by population, the generation of MSW, as well as the treatment of ash. It is not simply about getting rid of a waste product. As we will illustrate later, various local political and economic factors also affect the amount of ash traded.

There appears to be a constellation broadly linking to earlier EU members exporting to later EU ascension countries. This could be characterized as the externalization of waste or surplus ash (due to a high volume of incineration). Cluster 2 and Poland stand out as a telling case. Like other group members, its trade relations are almost as crucial as those within this network. Accordingly, it is safe to argue that Cluster 2, composed of Central and Eastern European countries, primarily depends on Cluster 1, which includes most of Western Europe's richest and most industrialized countries. Poland being its best-connected member in this group, similar to India discussed later, illustrates the growing significance of Central and Eastern Europe as a constellation.

First, Poland is an importer of EU garbage, and it expanded after China's 2017 ban on waste imports. Imports include legal and illegal exports from Germany and other countries. Unlike Western European countries, Eastern European countries such as Poland use landfills (Bronska

2021; Zimmerman 2021). Again, this is due to Poland's relative position in this constellation. This relationship, however, is a combination of both geography and economic power. German MSW firms can externalize environmental costs by exporting waste materials such as ash to Poland.

Second, while the import of waste includes garbage, Poland has limited incineration capacity. As such, there is pressure for Poland to expand its incineration capacity, supporting our argument regarding pressures to urbanize domestically and globally. Poland already has many more incinerators than its major ash trading partners in their cluster, for example, Lithuania, Hungary, and Slovakia (Confederation of European Waste-to-Energy Plants 2022). Notably, Polish cities are looking to expand their incineration capacity. For instance, the EU invested in incinerator projects in Gdańsk and Olsztyn to improve "waste management in the region" (European Commission 2020). Not coincidentally, these cities have seen urban renewal projects in recent years. The result is South Korean construction firm POSCO E&C developing an incinerator in Warsaw—which is anticipated to be the country's largest WtE plant. German firm Doosan Lentjes supplies various components for this project (Doosan Lentjes 2021). These projects intensify the connections both within and between different regional clusters of incinerated ash trade.

Third, it is essential to consider how this material is transformed into a commodity such as cement, which has a large international market. The connection, in part, has to do with cement kilns being used as incinerators (Mokrzycki, Uliasz-Bocheńczyk, and Sarna 2003). Thinking about materio-spatial and metabolic processes helps us understand urbanization in the global North. On the one hand, Poland has seen the rise of post-industrial sectors and a trend toward a polycentric urban landscape while its population remains flat (Kantor-Pietraga 2021; Bartosiewicz and Marcinczak 2022). On the other hand, Poland is the largest cement producer among central and eastern European countries. It also relies heavily on the neighboring EU members for trade. This is partly due to Belarus and Russia's trade restrictions with the EU, which have blocked their import of Polish cement (EU 2017; Ernst Young 2020).[5] International and local pressure influences Poland and this cluster's incineration capacity. In addition to wealthier countries investing in WtE, local industries, such as cement, can increase their market reach in nearby countries such as Hungary.

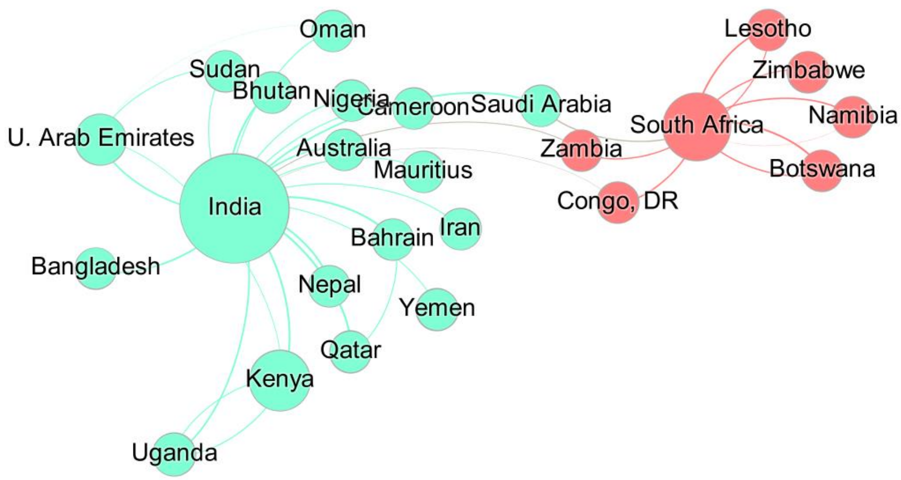
South-South

Most of the urbanization in the world is happening in the global South. As Indraphasta and Derudder (2019) have argued, the concept of the "world city" and related research has primarily come from the standpoint of the global North. Notably, they point to old narratives of modernization, whereby globalization and urbanization are endpoints. Such approaches essentialize and oversimplify the global South. Correspondingly, Bayat (2000: 554) has called attention to "larger structures and processes" to understand better the agencies involved in the

[5] A comparison could perhaps be made to Wallerstein's (2011b) observations regarding the grain trade between Holland and Eastern Europe in the late Middle Ages.

global South. Caldeira (2017), discussing urbanization in the periphery, notes that it involves many processes—including political practices that shape cities.

Figure 4: South-South Clusters



Source: UN Comtrade (2016–2020). Imports and Exports of 262110 - Slag and ash; ash and residues from the incineration of municipal waste. Visualization generated by Gephi 0.9.2.

As with North-North networks, uneven development plays a significant role in South-South relationships (See Figure 4). Much like countries in the North, regional powers in the South have comparatively more resources and bargaining power regarding trade. In turn, countries in the South-South network are characterized by semi-peripheral countries primarily trading with each other and those in the periphery. India is at the center of Cluster 3. In addition, Cluster 4 shows a South African network. As we saw from Table 1, India is a major global trader of incinerator ash, accounting for roughly 13 percent of the total global incinerated ash trade since 2002. Clusters 3 and 4 illustrate the importance of an Indian Ocean-based network of cities in rich and developing countries. Indian Ocean trade goes back centuries, connecting Southeast Asia to South Asia, the Middle East, and East Africa (Tagliacozzo 2002). It remains geopolitically and economically significant today as regional and global powers have deployed navies to protect trade routes from piracy (Kaplan 2009; Fatima and Jamshed 2020). Correspondingly, these networks are relevant in the trade of incinerator ash. India exports large amounts of incinerator ash to Qatar, Bahrain, Kenya, and Bangladesh. Here we see a constellation in which India's urbanization is connected to Doha, Manama, Nairobi, and Dhaka.

As with many countries in the East and global South, local and international pressures are to reduce waste and move away from fossil fuels. Concerns about climate change, pollution, and MSW have been growing in the global South just as they have in the global North. Yet, both clusters have seen a dramatic increase in waste imports since 2017. India, for example, imports garbage from North America and elsewhere, where it can fuel cement kilns, boilers, and furnaces

(Ha 2022). As with Poland, we also see proposals that Indian cement kilns rely on waste for energy with the idea that it can address local and global waste problems (Ghosh 2011).

Still, India and South Africa do not incinerate much of their waste. Lower-income countries generally produce less MSW than their counterparts in the global North. Due to local fuel sources and technological demands, they are far less likely to have efficient or large-scale waste incineration. India is the most critical trader in Cluster 3, but it is a relatively modest per capita producer of municipal solid waste. Notably, there is a higher percentage of organic waste than the material collected in Europe, which means its garbage generates less energy (Pati 2021). As such, it has very few operational plants, and several existing incinerators have been shut down. Of the active plants, four serve Delhi (Singh 2021). However, in 2017, the Indian government drafted a proposal to expand its WtE capacity dramatically. Despite significant protests, dozens of projects are underway (Sambyal, Agarwal, and Shrivastav 2019). Thus, the expansion of incineration in India is a relatively recent phenomenon as it imports more energy-rich fuel for incineration.

Similarly, there are calls for South Africa to expand its WtE capacity to deal with its MSW management problems and move away from coal power (Dlamini, Simatele, and Serge Kubanza 2019; Chivandire 2021). In the case of South Africa, this is complicated by the national utility company Electricity Supply Commission (ESCOM)'s monopoly and reliance on coal. Like cities in the global North, Cape Town has justified new WtE projects as an alternative to fossil fuels (Bugane 2017). Again, the pressure to expand WtE is a byproduct of materio-spatial and metabolic forces within the world-system. Local urban growth, industry, and energy demand within a global context are integral in understanding South Africa's place in trading incinerator ash. Like Poland, cement kilns are being used to incinerate trash, aiming to create what appears to be a circular economy (Department of Environmental Affairs and Tourism 2009). We see this on how Botswana is not only a major importer of South African bottom ash, but it is also an importer of its cement.

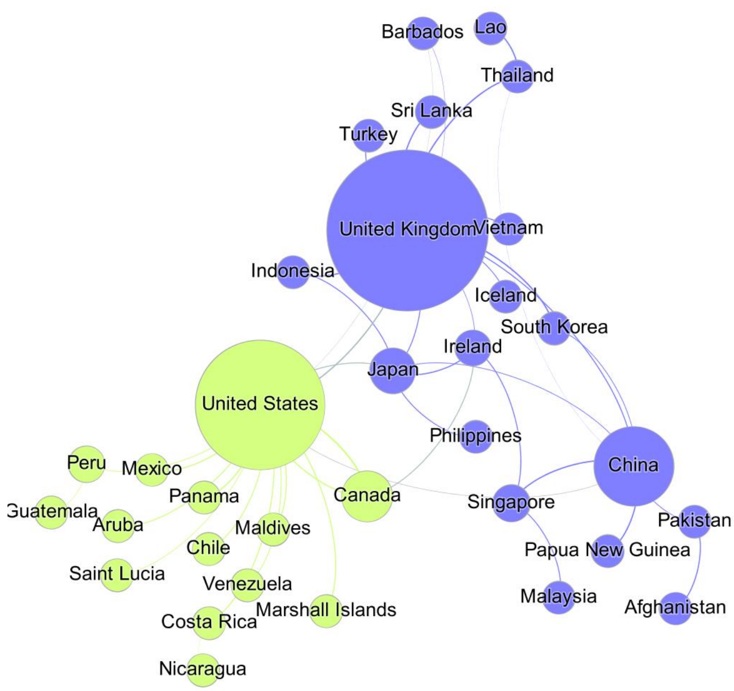
India, South Africa, and its regional trade partners are rapidly urbanizing. Local environmental concerns have exacerbated the global construction industry's demand for sand and international competition for it. The growing competition for sand disadvantages urbanizing countries in the global South. In particular, countries such as China have consumed global supplies to fuel their construction boom. India has also seen significantly increased demand. As such, it has slowly moved from local sand extraction to more significant imports following the passing of environmental protection laws in 2018. For instance, Mumbai's first WtE plant was recently approved with the condition that its ash be used for construction projects to address these problems (Singh 2022).

Important to note is that India also imports ash from the United Kingdom. Indeed, incineration happens less in India than in European countries. That said, scale must be considered. Not only are Indian cities rapidly growing, but its exports in incinerator ash are also linked to the fact that it is the world's second-largest cement producer (after China). Correspondingly, India has incentivized repurposing waste as fuel for cement plants and using bottom ash for construction (Mohapatra 2022; Perinchery 2022). As with Poland, we also see proposals that Indian cement kilns rely on waste for energy (Ghosh 2011). Here we see a constellation in which India's urbanization is connected to Doha, Manama, Nairobi, and Dhaka's growth.

North-South

Countries in the North-South network reflect traditional core, semi-peripheral, and peripheral relationships. Here, we are much more likely to see the trade of ash as a mechanism to externalize the cost of waste. The United States is primarily an exporter of ash. It is the best-connected country of Cluster 5 and is linked to smaller countries in South America (See Figure 5). While the United States has a strong network within the Americas, much of its ash goes to Europe. This is because the United States produces more MSW than any other country, and it has low recycling rates—including the use of incinerator ash. In fact, not traded ash often goes to landfills (Cho et al. 2020).

Figure 5: North-South Clusters



Source: UN Comtrade (2016–2020). Imports and Exports of 262110 - Slag and ash; ash and residues from the incineration of municipal waste. Visualization generated by Gephi 0.9.2.

Here we want to focus on Cluster 6, our study's "most global" cluster. The United Kingdom and China are this group's most-connected members and are part of a diverse constellation. Additionally, industrialized countries like South Korea, Malaysia, and Turkey, industrializing countries such as the Philippines and Vietnam, and developing countries such as Lao and Afghanistan are a part of this network. As Bunker (2005) argues, ecologically uneven development is an essential dimension of the functioning of the world-system. Uneven access to resources and sink capacity shapes the policy decisions of countries that trade incinerator ash.

Like South-South networks, we also see semi-peripheral countries playing a significant role. While the United Kingdom is clearly at the center of this network, China has a considerable impact. As mentioned earlier, in 2017, China announced that it would no longer take imports of foreign garbage. Going into effect in 2018, its Green Fence banned plastic waste imports, with restrictions on scrap paper and other materials put in place in later years. China's decisions represent a form of ecological modernization, whereby its leaders have argued that the move towards sustainability is integral to its economy (Brooks, Wang, and Jambeck 2018; Wen et al. 2021). Domestically, China is already one of the world's largest waste producers, including recyclables such as plastic. Correspondingly, they have significantly invested in incineration. In 2019, they had 389 incinerators (NBSC 2020). This was up from 188 in 2014 (NBSC 2015).

Interestingly, we find that despite China's massive investment in incinerators between 2016–2020, they were not exporting ash on the same scale as the countries mentioned in this study, e.g., the Netherlands, Poland, and India. This is likely due to its use in domestic construction projects. We also see that China is more interested in WtE projects in other countries. In 2016, Beijing Enterprises Holdings Ltd purchased EEW Energy in Germany. In Ethiopia, Chinese companies Cambridge Industries Ltd (CIL), its partner China National Electric Engineering Co (CNEEC), and Ramboll, a Danish engineering company, developed the Reppie WTE plant. Opening in 2017, it generates power from the waste collected in Addis Ababa, a growing regional hub (Wubneh 2013). As a build-operate-transfer project, operations were handed over to Ethiopian authorities in 2021.

Correspondingly, incinerator waste technology is exported in addition to the trade of ash. The North has significant advantages in terms of technology and related resources. In contrast, developing countries often depend on importing technology and associated services. This is most visible in China and countries such as South Korea and Japan. For instance, Hitachi Zosen Inova (HZI) is one of the largest WtE builders in the world. HZI is a Swiss subsidiary of the Japanese corporation Hitachi Zosen. Following the United Arab Emirates zero waste initiative in 2018, the company was contracted to build the world's largest WtE plant outside Dubai. In addition, Hitachi Zosen Inova helped build the first Turkish WtE plant in the Eyüp district of Istanbul.

Conclusion

Our typology suggests the following conclusions. First, the global trade networks of waste are not necessarily dominated by the old colonial powers or high-income countries. Poland, India, and South Africa are at the center of inchoate or fully-developed regional trade networks in which they have regional influence. Similarly, the United Kingdom heavily engages in a trade network beyond its older colonial sphere of influence. This network includes countries now economically much more influential, such as China. Second, we see a variety in terms of the regional scope of these networks. The North-South axis characterizes some of the networks but not all of them. Third, non-North networks entail a great deal of complexity. While some former Soviet Union countries operate in a small network under Russia there is another network between South Africa and its neighbors. India locates itself amidst a group of developing countries in the extended Indian Ocean network. Last, the analysis here couples the data on the MSW as a proxy for producing a critical industrial output in various urban settings with the data on the ash trade networks as a proxy for the productive consumption of this output. The exploratory potential of this approach could be helpful for future studies that connect city-level data to international commercial and industrial relations.

While WtE remains a robust sector in Europe, environmentalists have raised serious concerns regarding the dependency on burning trash (Gardiner 2021). Similarly, activists in the global South are fighting against incineration. Not only is it a form of greenwashing, but there is also a concern of opening Pandora's Box and becoming stuck on a treadmill where consumption is ever-increasing. Moreover, the colonial nature of some of these arrangements (e.g., the use of debt) is of concern. For example, Indian cities are interested in contracting with Chinese companies (Ferris 2013; Singh 2021). China has also expanded "green financial" instruments in Eastern and Southern Africa (Wass 2019; TBD Group 2020). As such, the trade of incinerator ash functions differently than for those in North-North relationships. This is less about the export of waste and more about the need to fuel urbanization and infrastructure development.

Cities and urban regions play a disproportionate role in resource consumption. The formation and reconfiguration of global trade networks among cities in materials such as incinerator ash can tell us about the power relations within those cities and their respective nation-states. The growing consumptive and productive share of the cities in the global trade networks in the incinerator ash and municipal solid waste possibly tells us a distinct story, which Samir Amin calls the "recompradorization" of the Third World (Amin 2011). This process is likely to significantly impact the local politics of those countries and, thereby, shape the modes of their engagement with global trade networks in various forms of waste. In order to study and reframe such and other connections, work must be done across the entire world-system of cities (Seitzinger et al. 2012). This requires a radical shift away from the expansion-oriented growth of capitalism towards self-renewing systems (Girardet 2014; Thomson and Newman 2018).

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