

Article

Flows as Makers and Breakers of Port-Territory Metabolic Relations: The Case of the Loire Estuary

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Abstract

Ports worldwide are shifting from their original locations, and the reasons behind these patterns of port development are multifaceted. Reasons for locational changes may include local factors such as natural conditions, or global trends like containerisation. This article argues that flows play a significant role in making and breaking metabolic relations between spaces. The authors use a combination of qualitative and quantitative approaches to characterise the evolution of port and territory interactions. A historical sequencing illustrates the successive phases of connection and disconnection between port and non-port spaces over the years. Drawing from the urban metabolism framework, the analysis of a port's traffic structure demonstrates how flows influence a port's extraterritoriality. For this research, the case of the Loire estuary was chosen: the Grand Maritime Port of Nantes Saint-Nazaire is a polycentric port that originated in Nantes and extended coastward in Saint-Nazaire. The case study reveals that a port reaching an urban area does not necessarily mean it will engage or support metropolitan development. Moreover, it concludes that flows are active drivers of territorial development in port regions. The research more broadly discusses the extraterritoriality of large logistics and transport infrastructure, like that of ports.

Keywords

flows; port; port-city; territoriality; urban metabolism

Issue

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1. Introduction

Seaports are strong logistic and industrial nodes in global supply chains that position port cities as entry points to globalisation and its effects (Hall, 2002). The irruption of global influences, exacerbated by technological advances such as containerisation, has in many ways disconnected ports from their local realities and ultimately transformed their relationship to their territory: physically, culturally, and spatially. Despite ongoing developments, most of the world's major container ports remain urban (Hall & Jacobs, 2012). An analysis of the successive connection and disconnection phases allows us to understand the renewed metabolic relations between

port and urban spaces and reveal the sociotechnical processes that shape the territory (Hein, 2014, 2016).

The Urban Metabolism (UM) framework understands spaces as made up of flows whose interactions are determinants for territorial development. Logistics is a driving force that shapes the relation between spaces and flows and can thus influence the territorial structure (Hesse, 2020). Port regions, in particular, represent points of intersection between global and local flows, where the two often overlap and momentarily merge. Such flows inevitably have an impact on the metabolic relations that shape the territories they reach. Ultimately, ports' *raison d'être* is to convey flows (Lévêque, 2014). As such, they continuously transform

their infrastructure and model to accommodate international trade and trends (Mat et al., 2016). As a result, ports tend to distance themselves from their birth territories and become extraterritorial to their host environment. Ironically, while bridging spaces, flows also deepen the alienation of critical infrastructure like ports. For this research, while we understand territories are made up of a variety of flows that are not quantified in port traffic reports (such as consumption and emissions), we have chosen to focus on import and export flows solely.

In what ways do flows shape territorial development and the metabolic relation between port and territory? Through a mixed methods approach, the article sheds light on several aspects of the relation and its evolution: A historical sequencing of port territory development illustrates the successive (dis)connection phases, while an in-depth analysis of the evolution of the regional port's traffic structure demonstrates the links between urban development and port operations. This encourages a discussion on flows as makers and breakers of metabolic relations (Clark, 1958) and drivers of territorial development.

The evolution of the relations between ports and cities, be it inland ports like Brussels, Strasbourg, or Paris (Beyer & Debie, 2011; Hall & Jacobs, 2012; Masy, 2020) or seaports like Antwerp, Rotterdam, or Hamburg (Hein & van Mil, 2019; van den Berghe, 2015) has been investigated many times over. This study instead concerns the case of the Nantes Saint-Nazaire port. The Loire estuary offers a particularly insightful context to explore the dynamics between a port and its host territory because its polycentric nature stretches from one city to another. Nantes is located up the Loire River, while St Nazaire is 63 km away at the very mouth of the river on the Atlantic coast. Until their reunion in 1966, the two cities hosted an inland port and a seaport. Granted the Grand Maritime Port status in 2008, along with seven other major ones, it is France's fourth port and the leading one of the Atlantic façade. The decisions to implement a set of dominating industrial activities and accommodate global flows through specific infrastructures within the port land have greatly impacted the relations between the port and its territory.

2. Theoretical Framework: Metabolic Flows Through the Port–Territory Relationship

2.1. The Evolution of the Port-Territory Dynamic

Port and city have long influenced each other and their relations and coevolution are the subject of extensive academic literature (Hall & Jacobs, 2012; Monios et al., 2018). Some scholars argue that the city entered the port and built around it (Norcliffe et al., 1996; Zheng et al., 2020), while for others, the port represents an addition or equipment to the city, part of a development strategy that faces issues of territorial insertion from the start (Foulquier, 2019). In many

cases, history has blurred the distinction between the two entities and merged them into coherent wholes (van den Berghe, 2015). “Portuality,” theorised by Moretti (2021), is a territorial quality that denotes those cities born and developed through strong historic/symbolic and economic/functional relations with their port. Territoriality expresses, in addition to a legal content of appropriation, a feeling of belonging but also of exclusion and a mode of behaviour within an entity, whatever its size and the social group that manages it (Steinberg, 1994). The concept has been applied to ports to understand the link between their traffic preferences and global positioning (Bridge & Bradshaw, 2017).

As cities urbanised and ports expanded, their co-development and co-existence extended to a larger geographical perimeter. Just as cities have found less need to be ports, ports have found good reasons not to be in cities (Norcliffe et al., 1996). The notion of the port-city interface has helped understand spaces where port and city interests overlap and often conflict (Aouissi et al., 2021; Daamen & Louw, 2016; Daamen & Vries, 2013; Hayuth, 1982; Hein & van Mil, 2019; Hesse, 2018; Hoyle, 1989; Hoyle et al., 1988). Many factors, across scales, have ultimately transformed the multi-faceted relationship between port and territory (Marcadon, 1999). While natural conditions at the individual level have driven ports out of their birth territory, so have human-enacted global trends. The downstream migration of port facilities is the most obvious physical manifestation of the disconnection between seaports and port cities (Hall, 2007). Starting in the 19th century with the industrial revolution, new port logics have structurally impacted port infrastructure and location (Bretagnolle, 2015; Hein, 2011, 2016; Olivier & Slack, 2006). The organisational and spatial revolution brought by containerisation since the 1960s radically changed the meaning of the flow/territory paradigm in the port sector (Lavaud-Letilleul, 2005). This applies to most large and medium-range ports, whether fluvial or seaside ones, older installations that remain in urban areas, or newer ones built in their periphery. This research addresses commercial ports and their industrial zones, disregarding ones that are marinas exclusively.

Consequently, new interfaces between the port and non-port developments are created (Hein, 2014). International examples illustrate the mushrooming of port infrastructures across the landscape, whether towards the sea or outward in the hinterland. In most cases, new hubs in the form of inland terminals or “dry ports” that guarantee critical volumes and more fluid flows appear (Cullinane et al., 2012; van der Horst & van der Lugt, 2011). As a consequence of the globalisation of the world economy, particularly the intensification of material and energy flows and the restructuring of production and distribution, ports are challenged to reassess their role in a system that is increasingly conceived of as global, not regional (Hesse, 2013). As they become pivotal nodes in these international chains (Hayuth,

1989; Hesse & Rodrigue, 2004; Slack, 1993), oriented around global logistics requirements rather than local ambitions, the port-city split has accentuated (Hall & Jacobs, 2012), leading to a loss of connection between the port and public local and regional institutions (Hein & van de Laar, 2020; Hesse, 2013; Moretti, 2017). Here, the concept of territoriality examines the management of equipment in and of itself, cut off from the territory (Collin, 2005). As the fracture deepens, ports have become extraterritorial to their local environs.

One critique of the Bird (1963), Hoyle (2000), and Norcliffe et al. (1996) models is that they are highly generic and non-situational. They attempt to explain the port-city interface based on supposed all-encompassing drives, with clear-cut geographic-economic models, concepts, and phases succeeding in time (Mazy, 2015). Although these models are helpful in comparing ports, they only justify general trends while ignoring divergent and singular scenarios. Based on abstract space, these models struggle to detect the processes behind the continued urban attachment of ports and the geographical scales at which this connection occurs (Hall & Jacobs, 2012). We argue that the connection or disconnection can be assessed through additional criteria beyond physical infrastructure. New methods must be developed to define the changing relationship between ports and their territory. Through the innovative use of UM, this research aims to contribute to the vast literature on ports' territorial insertion.

2.2. Metabolic Flows of Transit

This research presents a “follow the flow” approach to trace the historical development of a port region. The relations between territories and their environments are diverse and complex, with multiple impacts on various geographical and temporal scales. However, the physical dimension of these relations is often overlooked. The UM framework provides a comprehensive analysis of the interactions between a city and its local region by examining the energy and material flows within a nested and interconnected system. While traditional UM studies quantify energy and material flows, recent studies explore the qualitative aspects of the relationship between an entity and its environment through an analysis of the social processes that produce space. The current challenge to the UM framework is to integrate political, demographic, economic, and geographic factors that influence a region's metabolism and to examine the relations between material flows and their urban systems.

At the center of the UM methodology are the flows. Conveniently, the port's primary function is to transport flows in import/export traffic. While numerous studies have examined shipping cargo in relation to regional development (Notteboom & Rodrigue, 2005) and ecological transitions (Mat et al., 2016), there has been a lack of research specifically focused on port metabolism as

a concept. We argue the concept's application to ports supports an innovative exploration of the metabolic processes that shape a territory and help tell the story of a port's territorial integration. This research aims not to investigate the initial relation between port and city. It comes after the erosion of the long-standing symbiosis that once bridged the two (Norcliffe et al., 1996). It is to demonstrate the determinant role that flows play in the successive waves of connection and disconnection between port and territory.

3. Methodology: Historical Approach and Metabolic Traffic

By using the UM framework to analyse traffic flows, this research reveals different aspects of port-territory interactions beyond traditional economic analysis. It considers a more holistic understanding of the relations between a port and its surrounding region, taking into account social, environmental, and political factors. The mixed-methods approach advocated by Hein and van Mil (2019) also helps to bridge the gap between qualitative and quantitative approaches, providing a more nuanced understanding of the complex dynamics at play in port-territory relations.

3.1. Historical Sequencing Analysis

Historical sequencing provides a framework to illustrate the evolution of the relations between port and territory (Hein & van Mil, 2019; Mazy, 2020). This methodology borrows from path dependency in that it identifies critical junctures (Tasan-Kok, 2015) as pivotal turning points that mark phases of continuities and ruptures. By examining historical maps and public policy documents, it is possible to trace the successive developments that provoked connection and disconnection phases, which are linked to port flows and infrastructure accommodations. This approach provides a chronological account of how the port-territory relation has evolved over time.

3.2. Metabolic Port Traffic Analysis

The typology of ports proposed by Dooms and Haezendonck (2004) was originally developed to study inland ports: We enrich the method by using it to study a polycentric port that presents both inland and seaside features. The approach distinguishes between two types of ports based on their location characteristics and the presence of adjacent industrial clusters: “metropolitan-supporting” and “industry-supporting” ports. The former has a more urban and regional logistics functionality and is dominated by the distribution of construction materials by road, while the latter is less tied to its neighbouring urban centers and is characterised by a traffic structure dominated by oil products, coal, ores, and steel products. The application of this framework

to the Grand Maritime Port of Nantes Saint-Nazaire (GPMNSN) case study permits an exploration of the interaction between traffic flows and port infrastructure location, contributing to the overall development of the typology.

Following UM studies, we mobilised the Physical Trade Balance (PTB) indicator, which corresponds to imports minus exports. This is a key component of material flow analysis, one of the most robust tools used to measure the metabolism of a territory. The PTB is the physical equivalent of the monetary trade balance and measures the materials and energy that remain in the port before being consumed, shipped, or transformed. Understanding the material and energy flows transiting through and being consumed within a territory is crucial, and the PTB can facilitate the analysis of a territory's relation with its supply hinterland (Athanasiadis et al., 2018; Bahers et al., 2020). In this respect, the PTB is a first step in studying the material footprint of a territory (Eisenmenger et al., 2016; Wiedmann et al., 2015).

Imports and exports were measured using data from the port's statistical service (Nantes Saint-Nazaire Port, 2023) and from the archives of the regional statistical institute (for the data between 1955 and 2000), which were cross-referenced with Eurostat data on maritime transport. We developed a typology of merchandise per flow type:

- Oil/petroleum products: fossil fuels such as petrol, oil, and liquefied gas;
- Construction materials and minerals: building materials including sand, aggregates, cement, and wood;
- Biomass and agricultural products: fertilisers, animal feed, and human foodstuffs;
- Metals and manufactured products: metallurgical and manufactured articles made of ferrous or non-ferrous metals.

This typology draws from material flow analysis recognises these four major flows to be the most structuring for UM analysis (Bahers et al., 2018; Eurostat, 2018; Voskamp et al., 2017).

4. Results: The Territorial Development of Port–City Relations

4.1. Historical Sequencing

4.1.1. Preamble: A Historic Port-City

Nantes was considered the leading port in Europe as of 1704, with a tragically notable history in the slave trade. However, the estuary's silting up made it challenging for large vessels to reach Nantes. Consequently, outposts were developed where the cargo was received, loaded onto lighter boats, and transported to Nantes. The natural conditions are extensively documented as the estu-

ary's morphology directed all decisions (Vigarié, 1977). The territory's primary economic advantages are its central position on the Atlantic seaboard and the availability of vast areas of industrial land. These assets form the basis of the territory's economic ambitions, complemented by a deep-water port project.

4.1.2. 1850s: Saint-Nazaire Penhoët Dock

Thereafter, Nantes was gradually linked to the smaller town of Saint-Nazaire, conveniently located at the mouth of the estuary, through daily steamboats and the extension of the Orléans railway. The building of the Penhoët Dock in 1881 confirmed the coastal city's role as the forward port facility. The relationship between the two municipalities requires closer examination. Le Bras (1932) says the history of the relationship between Nantes and Saint-Nazaire is always evoked with diplomatic frankness. He frames the opposition as the classical one between an old and new city, in this case, the sea and estuary ports. Saint-Nazaire is wanted as an "annexe" or transit space to support the other's growth. Despite substantial blockage from Nantes, the Saint-Nazaire Chambre of Commerce was inaugurated, shifting from a relation of subordination to one of independence. Upon the end of the First World War, a regional study committee was created to develop and ensure the planning of works of common interest. A period of connection and integration succeeded one of strong opposition: While the old city modernised, the new one became centenary (Le Bras, 1932). The Loire estuary bore the promise of a western metropolis that spread from Nantes to Saint-Nazaire. Yet the two do not have a natural tendency to come together: They are separated by vast unurbanised spaces that can remain so without jeopardising metropolitan construction, provided that the two centers find functional links (Cabanne, 1972).

4.1.3. 1966: One Port Authority

From the start of the project, the port served as the center of the new two-headed metropolis device (Place publique Nantes/Saint-Nazaire, 2007). In 1966, the once-distinct ports were merged under a single public enterprise: the Autonomous Port Authority of Nantes Saint-Nazaire. The first challenge posed by the creation of the autonomous port was to find ways of balancing the two different heads. To strengthen Saint-Nazaire's potential to play the role, it needed to raise the "critical mass" from which it could assume new responsibilities (Vigarié, 1980). Two development strategies were proposed for the "Atlantic façade" project: one entirely oriented towards export by sea regardless of the hinterland, and the other advocated for the region's development as an ocean frontage of a French and even European entity. The first justified the establishment of industries that did not appear profitable given the conditions of the regional

and national consumer markets, but which would be if they are destined for overseas markets. These would include basic industrial forms of production such as coal, steel, and petrochemicals. The second direction sought to rely initially on existing medium and light industries, in particular food industries favoured by an important agricultural potential, and high-tech industries, to create a growing demand for basic products which would eventually call for, in later stages of development, the establishment of heavy industries. As if to seal the deal, the master plan for the development by 1985 of the Autonomous Port stated that the port offer would “be mainly oriented towards industry” (Cabanne, 1972).

4.1.4. 1970s Onwards: Montoir and the Exponential Industrialisation of the Estuary

Natural conditions determined the locations of industrial-port zones near medium and large seaports in France (Vigarié, 1977). Montoir and Donges (see Figure 1) were selected due to their greater accessibility for large ships and the available space for the development of heavy industrial production (Marcadon, 2021). A liquefied natural gas terminal and a container terminal opened in the following decade (Noyer & Patillon, 2012). The development of the poly-industrial port in Montoir, alongside the expansion of Donges through the interplay of created jobs, would bring Saint-Nazaire to the urban level from which a higher tertiary role could be established on solid foundations. Thus, in its initial

conception, Montoir and its port appeared as instruments to serve regional development in the metropolitan sense. International shipping was a means, not an end (Vigarié, 1980).

Despite benefiting its immediate urban areas, the industrial hub became disconnected from them (Marcadon, 2021). The transfer of port activity downstream did not spur urbanisation. Instead, the town of Saint-Nazaire (with a population of 68,300 in 1982, in an agglomeration of 130,000) developed around a dominant industrial activity—shipbuilding and aeronautics—that had originally operated in Nantes. As part of the national deindustrialisation trend starting in the mid-1970s, this city gradually dropped its industrial function (Cabanne, 1990). Historians distinguish one estuary, two cities, and three maritime hubs, with Donges-Montoir as its leading powerhouse. In 1983, the quays of Nantes loaded or unloaded only 1.6 million tons of goods, compared to 10.4 million tons at Donges and nearly 7.5 million at Montoir. As a result, over 85% of the traffic of the Loire port took place downstream in the estuary. However, Saint-Nazaire did not benefit from this traffic: Since its docks did not meet modern conditions for maritime traffic, everything was concentrated in Donges and Montoir, where polyfunctional port installations had been established for several years (Cabanne, 1985).

On the other hand, Nantes retains full control of its port tool, which is located mostly outside the urban space. The Autonomous Port’s headquarters were

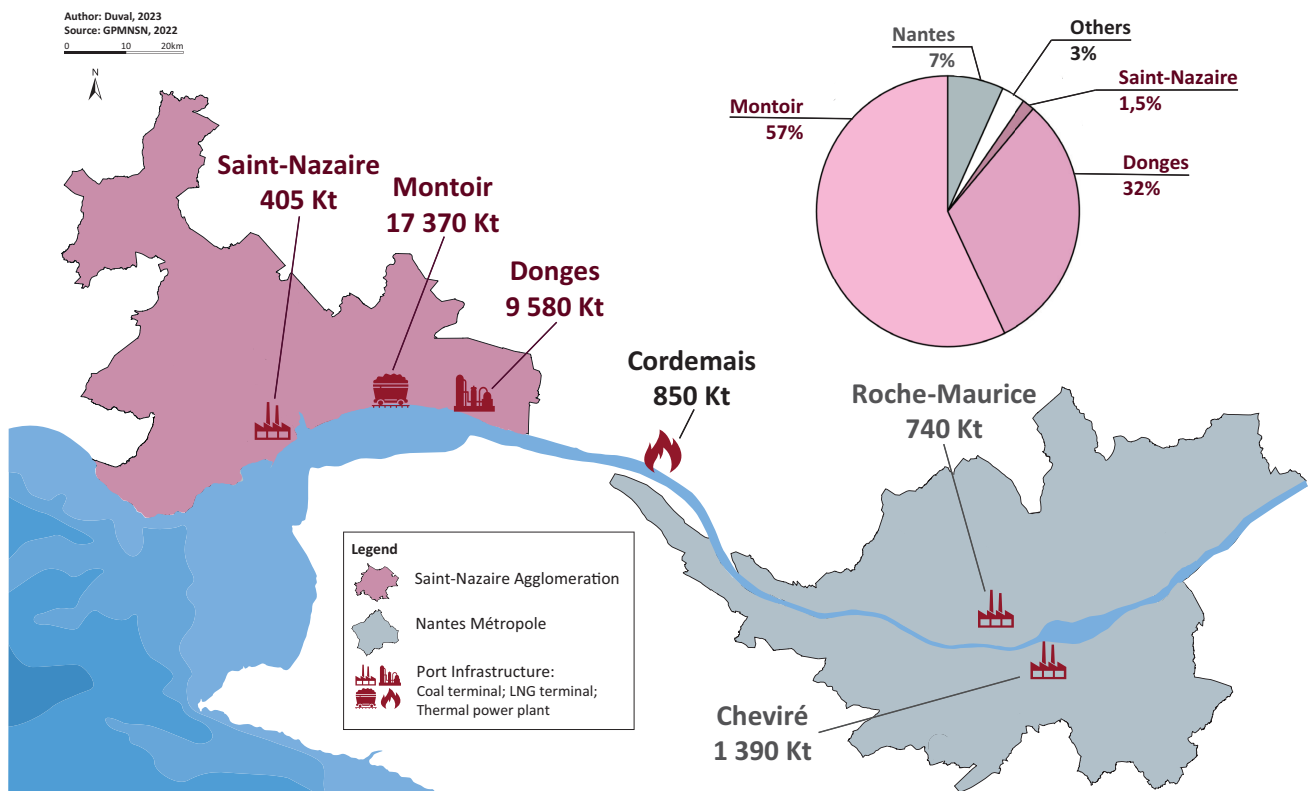


Figure 1. GPMNSN infrastructure and traffic structure. Source: Adapted from Nantes Saint-Nazaire Port (2023).

moved from the center of Nantes to a suburban area, symbolising the spatial separation of the port from the city. However, this move anchored the management of the port in Nantes rather than in the new technical installations of Montoir, which was also a possibility at the time (Cabanne, 1985).

4.1.5. 2008: Port Reform

The 2008 national port reform aimed to enhance the competitiveness of the metropolitan autonomous ports and transform them into major seaport authorities at the European level. As part of this reform, the GPMNSN was established, which marked a significant turning point in regional governance. The GPMNSN gained greater independence from local government, while also extending the representation of local governments in the port’s governance bodies. In 2019, Christelle Moranaçais, the chair of the region, was elected as the head of the Supervisor Board, reflecting a renewed collaboration between the economic and territorial stakeholders of the estuary. This indicates a desire to reconnect the port with its territory, rather than just the two municipal governments of the two cities as was once needed.

In practice, today the polycentric port reveals an unequal distribution of activities across its infrastructure. The diagram in the previous section (Figure 1) displays the percentage of the overall GPMNSN traffic per location, highlighting that most cargo is handled outside of the two core urban centers. However, this alone does not suffice to indicate a disconnection between the port and metropolitan areas.

The qualitative analysis of the port’s territorial development indicates a trajectory of successive (dis)connections between the two urban agglomerations and their port. Ironically, while the port originally served as a catalyst for the cities’ merging, it has since grown as an independent center. Much of the existing case studies

and theoretical models in the academic literature theorise and demonstrate a disconnection between city and port through simple notions of geographical distancing. We argue that geographic proximity is insufficient and that the study of flows helps to reveal further the nature of the links between the port and its territory. The analysis of the traffic flows, in the next section, informs the evolution of the metabolic relations between urban and port elements of the Loire estuary.

4.2. Traffic Structure Analysis

In practice, the GPMNSN’s contemporary facilities are scattered along the estuary with a growing presence on the coast, encompassing twenty-two communes and five intercommunal structures. Figure 1 illustrates the location of the port infrastructure, and distinguishes which belong to the Nantes and Saint-Nazaire metropolitan areas. At the global level, ports are ranked per their annual tonnage. Figure 1 also details the tonnage each infrastructure handles (for the year 2022). The Nantes Métropole area operates 10% of the overall traffic, comparable to smaller ports like that of Brest or Lorient. While the two most significant facilities, Donges and Montoir, belonging to the Saint-Nazaire Agglomeration area, amount to 57% and 32%, respectively (Nantes Saint-Nazaire Port, 2023). Drawing from this first analysis, one can infer that port operations are more closely associated with Saint-Nazaire than they are with Nantes.

The following analysis aims to investigate the traffic structure to characterise the nature of the relation between the city/territory and the port. Figure 2 displays the evolution of the GPMNSN traffic structure between 1955 and 2022. The data used to produce the graph and analysis were obtained from the port’s statistical service (Nantes Saint-Nazaire Port, 2023) and the archives of the regional statistical institute for the period between 1955 and 2000. The data is divided into four

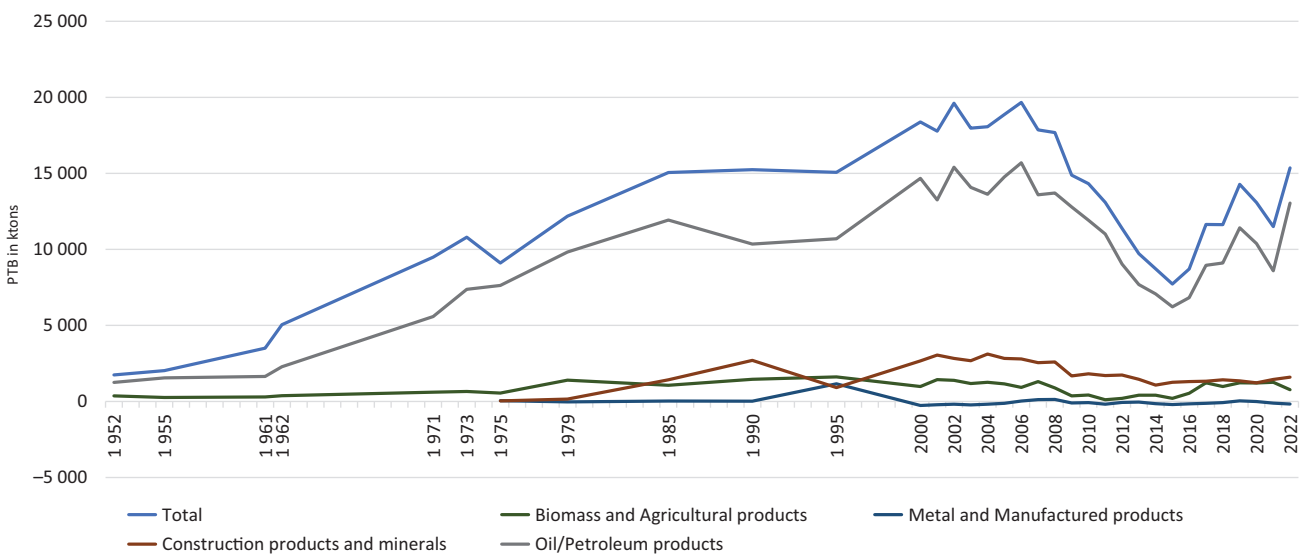


Figure 2. PTB (Traffic) of GPMNSN.

major categories of merchandise. The PTB corresponds to imports minus exports.

Figure 2 makes legible three important factors of port activity. First, imports exceed exports. For example, in 2022, the traffic of the port of Nantes Saint-Nazaire amounted to more than 29.7 million tons, of which 76% were imports (Nantes Saint-Nazaire Port, 2023). Therefore, the port primarily serves as an import hub for the consumption of goods and raw materials, rather than an export hub for hinterland products.

Secondly, most of the PTB is in the form of liquid bulk, such as crude oil, refined products, and natural gas. This is characteristic of an industry-supporting port, according to the established typology of flows. The planning and building of the Montoir-Donges port hub are intimately tied to the development of petroleum exploitation. In 1953, hydrocarbon traffic was already the main item in most major French ports, but its share represented less than two-thirds of entries and exits (2.1 out of 3.4 million tons). In fact, the prioritisation of petroleum/oil products in the Loire estuary port was an effort by local port authorities to adapt to global traffic needs (Cabanne, 1984). In 2022, the share of energy flows exceeded two-thirds of total traffic (69%) compared to just over half in 2021 (55%). This increase was partly due to the global energy crisis resulting from Putin's invasion of Ukraine. Like many European countries, France needed to secure its energy supplies in anticipation of winter 2022/2023 (Nantes Saint-Nazaire Port, 2023).

Thirdly, the other three main flow types (biomass, metal, and construction products) have remained relatively constant in tonnage over the years. This indicates that the port model has stabilised, despite spikes caused by global economic crises. It also implies that the metabolic relations between the port and the territory have remained unchanged. In other words, the port has continued to serve and grow its industry base, maintaining a coherent role in the territory.

Based on the hypothesis of Dooms et al. (2013), the traffic structure of GPMNSN suggests that it was intended to be an extraterritorial port, primarily serving industrial activities rather than directly catering to urban and regional economies and their populations. Consequently, we can infer that while the port has grown physically separating from the metropolitan area, it has also become disconnected from the urban system. The industrial zone of the port has expanded to the point where it dominates the overall port operations, at the expense of developing metropolitan-oriented activities.

5. Discussion: Territoriality of Metabolic Interactions

The worldwide-observed phenomenon of ports moving outside their birthplaces served as a starting point for this research: Scientific models account for their joint development, gradual disconnection, and other causes of the geographic and economic disarticulation of ports and cities. Global trends such as industrialisation and

globalisation, in addition to local factors (such as changing ecological conditions), explain the choices made relating to port infrastructure. As ports become more deeply embedded in global supply chains, their administrative bodies undertook transformations to accommodate further global connection and commerce. In doing so, ports grew separate from their local realities, including that of surrounding urban areas, and ultimately became extraterritorial to their environment.

This article discusses the attenuation of the attachment of ports to their neighbouring urban areas and the changing metabolic relations between the port and non-port territorial elements. The history discussed above illustrates the strong ties that the city of Nantes initially had with the regional port. Early on, however, the difficulty of navigation on the Loire and accessibility were put forward as motives to forsake Nantes for a more coast-ward location. As water transport was cheaper than rail, port infrastructure was continuously relocated and built towards the ocean. Nantes and the port operated successfully and profitably until the orchestrated rise of Saint-Nazaire as the primary platform for maritime goods. For example, according to our results from the analysis of archival data, the port of Nantes accounted for 52% of traffic in 1952, whereas it represented only 30% in 1961 (70% for Saint-Nazaire and Donges). After a sequence of connections, the construction and operation of the Saint-Nazaire docks began to disconnect the birth city and port resulting in a trajectory of disarticulation that has continued until today. A century later, the port served as a medium through which to merge the two cities within a joint port authority; a brief connection interlude that may have had more to do with regional power relations than accommodating material flows. While the relationship between Nantes and the port was final, one could have expected the port to interweave with the urban fabric of Saint-Nazaire. Yet, historical and qualitative analysis reveals the migration of port facilities westward, and the construction of newer ones closer to Saint-Nazaire did not bring the city and port "closer together." Coincidentally, the next phase (of disconnection) unfolded as the port grew a center of its own, separate from the urban ones nearby, with the rise of the Montoir and Donges facilities. Today, the port appears disconnected from both metropolitan areas, and more closely associated with global flows of commodities than local and regional economies. The GPMNSN is neither a bridge nor a break between the two cities of Nantes and Saint-Nazaire. Instead, it is a third entity to acknowledge, an industrial enclave: both geographically and in its model's orientation.

The study of flows provides significant insight into the interactions between ports and territories, as well as their evolution. Clark (1958) discussed the ambivalent role of transport as both makers and breakers of cities. Here, we demonstrate the role of flows in port infrastructure planning. This article defines flows as the essence of the metabolic relation between port and

non-port. Thus, they can potentially break port-territory relations and drive a port's developmental trajectory towards extraterritoriality. We determined the port's territorial integration by analysing the (dis)connection between the port and the territory. While flows do not have the agency to concretely take part in decision-making, their vital importance to port growth manifests in the numerous port infrastructure modifications that were made to accommodate them. The traffic of energy flows increased for 30 years, between 1975 and 2006. Despite experiencing several successive crises, it remains the most significant share of the port's overall traffic. The GPMNSN has thus become a vital energy installation at both local and national levels. It, therefore, comes as no surprise that transformations are carried out to ensure the successful handling of (fossil) energy flows in the port. Our methodology, drawn from Doooms and Haezendonck's framework (2004), identifies the preponderance of oil and petroleum products in the port's traffic share as factors in a port's extraterritoriality because it favours the development of the industry rather than metropolitan-oriented activities. The presence of an industrial zone adjacent to or within an urban area can be considered a benefit to the nearby metropolis. Although each fuel the others, industrial operations are in many ways separate from metropolitan-supporting ones. Indirect benefits may not justify the continued presence of industrial activities within metropolitan areas. Much like industrial areas within urban ones do not necessarily indicate a connection or joint development. Our analysis of the GPMNSN's traffic structure revealed it to be an industry-supporting port. Moreover, our case study supports our claim that flows are drivers of territorial development, as the decisions made to accommodate them can be directly tied to sequences of connection and disconnection between port and territory.

Numerous scholars have examined the disconnection of ports from cities/territories through abstract models (Bird, 1963; Hoyle, 1989) and others through historical sequencing (Hein & van Mil, 2019; Masy, 2020). Flows in ports have been extensively studied in exploring the globalisation of port cities (Ghiara & Sillig, 2008) and the search for increased competitiveness (Hein, 2016). However, flows have rarely been investigated as bridges or obstacles to territorial integration. This article proposed a mixed-methods approach to shed light on the role that flows play in port-territory dynamics. It foregrounds the central role flows play in creating and disrupting metabolic relations between spaces and in causing the parallel development of port and non-port. Throughout this research, the term "port" is used to contrast with "non-port," "territory," "city," and "metropolitan area" to emphasise a comprehensive distinction. This research demonstrated the disconnection between the two in the Loire estuary despite the continued presence of port infrastructure in metropolitan areas. We believe this innovative approach, inspired by methodologies derived from the UM framework, to be

insightful in informing another facet of port-territory relations. One that most models overlook.

6. Conclusion

This article explored the role of flows in influencing the territorial development of port regions and metabolic relations between port and host territory. The study was conducted in two stages. First, the historical evolution of the port in its region and its relations with neighbouring urban areas were revealed through an analysis of historical sequencing. Significant events related to port growth and flow accommodation were identified as transitions from connection to disconnection phases. Second, contemporary port-territory interactions were analysed through a thorough traffic structure analysis. The case of the Loire port of Nantes Saint-Nazaire proved particularly insightful as it presents a polycentric port that has expanded over the years from one city to another. Until the mid-twentieth century, the main concern was the (dis)connection between Nantes and Saint-Nazaire. In contemporary times, the article examined the (dis)connection of the port from its territory. The dominant oil and petroleum flow type is directly identified as a factor of this disconnection, indicating a preference for industry over metropolitan activities. The authors deem this port type to be extraterritorial. The use of mixed methods provided a comprehensive understanding of the nature of the metabolic relations between port and territory. Both the geographical relocation assessment and the in-depth study of port traffic structure corroborated the hypothesis that the Loire estuary port was disconnected from its territory, despite its infrastructure remaining located within two large metropolitan areas. We believe that UM is an innovative tool for studying territorial development that can help reveal the multifaceted interactions that shape spaces.

Considering the extraterritoriality of ports, the industrial enclave it represents can be an obstacle to the implementation of regional development strategies. As ecological challenges reaffirm their urgency, the necessity to collaborate with the port in the Loire estuary grows. While the energy transition and circular economy gain momentum, one can assume their implementation might rekindle dialogue between the port and territorial actors while weaving energy and material flows of the port and urban systems together, thus enabling a new connection phase. This article calls for future research on the role of ports in setting up ecological transitions.

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Conflict of Interests

The authors declare no conflict of interests.

References

- Aouissi, K. B., Madani, S., & Baptist, V. (2021). Morphological evolution of the port-city interface of Algiers (16th century to the present). *Urban Planning*, 6(3), 119–135.
- Athanassiadis, A., Christis, M., Bouillard, P., Vercauteren, A., Crawford, R. H., & Khan, A. Z. (2018). Comparing a territorial-based and a consumption-based approach to assess the local and global environmental performance of cities. *Journal of Cleaner Production*, 173, 112–123.
- Bahers, J. B., Barles, S., & Durand, M. (2018). Urban metabolism of intermediate cities: The material flow analysis, hinterlands and the logistics-hub function of Rennes and Le Mans (France). *Journal of Industrial Ecology*, 23(3), 686–698.
- Bahers, J. B., Tanguy, A., & Pincetl, S. (2020). Metabolic relationships between cities and hinterland: A political-industrial ecology of energy metabolism of Saint-Nazaire metropolitan and port area (France). *Ecological Economics*, 167, 106–447.
- Beyer, A., & Debrie, J. (2011). Les temporalités frontalières et urbaines du port de Strasbourg. Analyse géohistorique d'une relation fluviale ville-port [The border and urban temporalities of the port of Strasbourg. Geohistorical analysis of a city-port river relationship]. *Métropoles*, 10. <https://doi.org/10.4000/metropoles.4494>
- Bird, J. H. (1963). *The major seaports of the United Kingdom*. Hutchinson.
- Bretagnolle, A. (2015). City-systems and maritime transport in the long term. In C. Ducruet (Ed.), *Maritime networks* (pp. 51–60). Routledge.
- Bridge, G., & Bradshaw, M. (2017). Making a global gas market: Territoriality and production networks in liquefied natural gas. *Economic Geography*, 93(3), 215–240.
- Cabanne, C. (1972). Regards sur l'aménagement de l'estuaire de la Loire [Views on the development of the Loire estuary]. *L'Espace géographique*, 4, 269–274.
- Cabanne, C. (1984). Transformation de l'activité portuaire dans l'estuaire de la Loire [Transformation of port activity in the Loire estuary]. *Cahiers du Centre nantais de recherche pour l'aménagement régional*, 1984(26), 89–93. <https://doi.org/10.3406/canan.1985.1456>
- Cabanne, C. (1985). Nantes-Saint-Nazaire vers le large [Nantes-Saint-Nazaire offshore]. *Norois*, 126, 269–272. <https://doi.org/10.3406/noroi.1985.4239>
- Cabanne, C. (1990). Nantes, de la ville industrielle à la ville tertiaire [Nantes, from industrial city to tertiary city]. *Cahiers du Centre nantais de recherche pour l'aménagement régional*, 1990(33/34), 185–197.
- Clark, C. (1958). Transport: Maker and breaker of cities. *The Town Planning Review*, 28(4), 237–250.
- Collin, M. (2005). Nouvelles mobilisations productives des territoires autour des ports et des aéroports [New productive mobilisations of territories around ports and airports]. In A.-G. Aubert & S. Guth (Eds.), *Déplacements : Architectures du transport, territoires en mutation* [Travel: Transport architectures, changing territories] (pp. 129–136). Recherches IPRAUS.
- Cullinane, K., Bergqvist, R., & Wilmsmeier, G. (2012). The dry port concept—Theory and practice. *Maritime Economics & Logistics*, 14(1), 1–13.
- Daamen, T., & Louw, E. (2016). The challenge of the Dutch port-city interface. *Tijdschrift voor economische en sociale geografie*, 107(5), 642–651.
- Daamen, T. A., & Vries, I. (2013). Governing the European port-city interface: Institutional impacts on spatial projects between city and port. *Journal of Transport Geography*, 27, 4–13.
- Haezendonck, E., & Doods, M. (2004, August 25–29). *An extension of 'green port portfolio analysis' to inland ports: An analysis of a range of eight inland ports in Western Europe* [Paper presentation]. ERSA 2004: 44th Congress of the European Regional Science Association, Porto, Portugal.
- Doods, M., Verbeke, A., & Haezendonck, E. (2013). Stakeholder management and path dependence in large-scale transport infrastructure development: the port of Antwerp case (1960–2010). *Journal of Transport Geography*, 27, 14–25.
- Eisenmenger, N., Wiedenhofer, D., Schaffartzik, A., Giljum, S., Bruckner, M., Schandl, H., Wiedmann, T. O., Lenzen, M., Tukker, A., & Koning, A. (2016). Consumption-based material flow indicators—Comparing six ways of calculating the Austrian raw material consumption providing six results. *Ecological Economics*, 128, 177–186.
- Eurostat. (2018). *Economy-wide material flow accounts handbook: 2018 edition*. Publications Office of the European Union. <https://data.europa.eu/doi/10.2785/158567>
- Foulquier, E. (2019). Transport maritime et changements climatiques. Mise en perspective en géographie [Maritime transport and climate change. Perspectives in Geography]. *Le Droit Maritime Français*, 815, 581–589.
- Ghiara, H., & Sillig, C. (2008). Les territoires du port. Le cluster portuaire et logistique génois [The territories of the port. The Genoese port and logistics cluster]. *Méditerranée. Revue géographique des pays méditerranéens*, 111, 25–30.
- Hall, P. V. (2002). *The institution of infrastructure and the development of port-regions*. University of California Transportation Center.
- Hall, P. V. (2007). Seaports, urban sustainability, and paradigm shift. *Journal of Urban Technology*, 14(2), 87–101.

- Hall, P. V., & Jacobs, W. (2012). Why are maritime ports (still) urban, and why should policy-makers care? *Maritime Policy & Management*, 39(2), 189–206.
- Hayuth, Y. (1982). The port-urban interface: An area in transition. *Area*, 14(3), 219–224.
- Hayuth, Y. (1989). Editor's introduction: The dynamics and dimensions of port—City interrelationships. *Geoforum*, 20(4), 427.
- Hein, C. (2011). Port cityscapes: A networked analysis of the built environment. In C. Hein (Ed.), *Port cities: Dynamic landscapes and global networks* (pp. 1–24). Routledge.
- Hein, C. (2014). Port cities and urban wealth: Between global networks and local transformations. *International Journal of Global Environmental Issues*, 13(2/4), 339–361.
- Hein, C. (2016). Port cityscapes: Conference and research contributions on port cities. *Planning Perspectives*, 31(2), 313–326.
- Hein, C., & van de Laar, P. T. (2020). The separation of ports from cities: The case of Rotterdam. In A. Carpenter & R. Lozano (Eds.), *European port cities in transition* (pp. 265–286). Springer.
- Hein, C., & van Mil, Y. (2019). Towards a comparative spatial analysis for port city regions based on historical geo-spatial mapping. *PORTUSplus*, 8, 2–18. <https://www.portusplus.org/index.php/pp/article/view/189>
- Hesse, M. (2013). Cities and flows: Re-asserting a relationship as fundamental as it is delicate. *Journal of Transport Geography*, 29, 33–42.
- Hesse, M. (2018). Approaching the relational nature of the port-city interface in Europe: Ties and tensions between seaports and the urban. *Tijdschrift voor economische en sociale geografie*, 109(2), 210–223.
- Hesse, M. (2020). Logistics: Situating flows in a spatial context. *Geography Compass*, 14(7), Article e12492. <https://doi.org/10.1111/gec3.12492>
- Hesse, M., & Rodrigue, J. P. (2004). The transport geography of logistics and freight distribution. *Journal of Transport Geography*, 12(3), 171–184.
- Hoyle, B. (2000). Global and local change on the port-city waterfront. *Geographical Review*, 90(3), 395–417.
- Hoyle, B. S. (1989). The port–city interface: Trends, problems and examples. *Geoforum*, 20(4), 429–435.
- Hoyle, B. S., Pinder, D. A., & Husain, M. S. (1988). *Revitalising the waterfront: International dimensions of dockland redevelopment*. Belhaven Press.
- Lavaud-Letilleul, V. (2005). L'aménagement de nouveaux terminaux à conteneurs et le renouvellement de la problématique flux-territoire dans les ports de la Rangée Nord [The development of new container terminals and the renewal of the flow-territory issue in the ports of the North Row]. *Flux*, 1, 33–45.
- Le Bras, G. (1932). Les ports de la basse Loire [The ports of the lower Loire]. *Annales d'histoire économique et sociales*, 4(15), 308–311.
- Lévêque, L. (2014). Du cluster portuaire au système portuaire régional: Des territoires structurés par la gestion des flux de marchandises [From the port cluster to the regional port system: Territories structured by the management of the flow of goods]. In *CIST2014 Fronts et frontières des sciences du territoire* [CIST2014 2 International Conference: Frontiers and boundaries of territorial sciences] (pp. 262–270). GIS Collège international des sciences du territoire.
- Marcadon, J. (1999). Containerisation in the ports of Northern and Western Europe. *GeoJournal*, 48, 15–20.
- Marcadon, J. (2021). André VIGARIÉ et l'aménagement de la Basse-Loire: Mise en perspective [André VIGARIÉ and the development of the Basse-Loire: in perspective]. *Numéros*, 1, 73–81.
- Masy, K. (2020). The evolution of the relationship between inland ports and cities: The cases of Brussels and Lille. *PORTUSplus*, 10, 2–20. <https://www.portusplus.org/index.php/pp/article/view/210>
- Mat, N., Cerceau, J., Shi, L., Park, H. S., Junqua, G., & Lopez-Ferber, M. (2016). Socio-ecological transitions toward low-carbon port cities: Trends, changes and adaptation processes in Asia and Europe. *Journal of Cleaner Production*, 114, 362–375.
- Mazy, K. (2015). *Villes et ports fluviaux: Les conditions d'une reconnexion* [Cities and river ports: The conditions for reconnection] [Unpublished doctoral dissertation]. Université des Sciences et Technologie de Lille; Université Libre de Bruxelles.
- Monios, J., Bergqvist, R., & Woxenius, J. (2018). Port-centric cities: The role of freight distribution in defining the port-city relationship. *Journal of Transport Geography*, 66, 53–64.
- Moretti, B. (2017). Port city borderscapes: Origin, nature and evolution of the administrative boundary. In G. Pellegrini (Ed.), *De-sign environment landscape city* (pp. 251–262). David and Matthaues.
- Moretti, B. (2021). The port city. In B. Moretti (Ed.), *Beyond the port city* (pp. 25–40). JOVIS Verlag GmbH.
- Nantes Saint-Nazaire Port. (n.d.). *The port's history*. <https://www.nantes.port.fr/en/nantes-saint-nazaire-port/ports-history>
- Nantes Saint-Nazaire Port. (2023, January 6). *Le port du Grand Ouest au coeur des enjeux énergétiques nationaux et internationaux* [The port of the Great West at the heart of national and international energy issues] [Press release]. https://www.nantes.port.fr/sites/default/files/medias/CP_Trafics%20portuaires%202022_NSNP.pdf
- Norcliffe, G., Bassett, K., & Hoare, T. (1996). The emergence of postmodernism on the urban waterfront: Geographical perspectives on changing relationships. *Journal of Transport Geography*, 4(2), 123–134.
- Notteboom, T. E., & Rodrigue, J.-P. (2005). Port regionalization: Towards a new phase in port development. *Maritime Policy & Management*, 32(3), 297–313.
- Noyer, M., & Patillon, C. (2012). La fin d'un monde? [The

- end of the world?]. *Vingtième Siècle. Revue d'histoire*, 116(4), 109–120.
- Olivier, D., & Slack, B. (2006). Rethinking the port. *Environment and Planning A*, 38(8), 1409–1427.
- Place publique Nantes/Saint-Nazaire. (2007). *L'estuaire de la Loire. Un territoire à réinventer* [The Loire estuary. A territory to reinvent]. <https://www.revue-placepublique.fr/Sommaires/Sommaires/sommaire3.html>
- Slack, B. (1993). Pawns in the game: Ports in a global transportation system. *Growth and Change*, 24(4), 579–588.
- Steinberg, P. E. (1994). Territory, territoriality and the new industrial geography. *Political Geography*, 13(1), 3–5.
- Tasan-Kok, T. (2015). Analysing path dependence to understand divergence: Investigating hybrid neo-liberal urban transformation processes in Turkey. *European Planning Studies*, 23(11), 2184–2209.
- van den Berghe, K. (2015, March 23–26). *Beyond geographic path dependencies: Towards a post-structuralist approach of the port-city interface* [Paper presentation]. AESOP Young Academics Conference, Palermo, Italy.
- van der Horst, M. R., & van der Lugt, L. M. (2011). Coordination mechanisms in improving hinterland accessibility: Empirical analysis in the port of Rotterdam. *Maritime Policy & Management*, 38(4), 415–435.
- Vigarié, A. (1977). Présentation morphologique de l'estuaire de la Loire: Ses conséquences pour l'aménagement [Morphological presentation of the Loire estuary: Its consequences for development]. *Cahiers Nantais*, 13(1), 69–81.
- Vigarié, A. (1980). Evolution et avenir des zones industrielles et portuaires [Evolution and future of industrial and port areas]. *L'information géographique Paris*, 44(4), 145–153.
- Voskamp, I. M., Stremke, S., Spiller, M., Perrotti, D., van der Hoek, J. P., & Rijnaarts, H. H. (2017). Enhanced performance of the Eurostat method for comprehensive assessment of urban metabolism: A material flow analysis of Amsterdam. *Journal of Industrial Ecology*, 21(4), 887–902.
- Wiedmann, T. O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., & Kanemoto, K. (2015). The material footprint of nations. *Proceedings of the National Academy of Sciences*, 112(20), 6271–6276.
- Zheng, Y., Zhao, J., & Shao, G. (2020). Port city sustainability: A review of its research trends. *Sustainability*, 12(20), Article 8355. <https://doi.org/10.3390/su12208355>

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