CIRCULAR FOAM

Regional economic structures and situation

D1.3

Author:

Forschungszentrum Jülich GmbH (FZJ)
Institute of Energy and Climate Research – Systems Analysis and Technology Evaluation (IEK-STE)

Dr. Imke Rhoden, Dr. Andrew Ross

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Executive Summary

This analysis delves into the economic interlinkages and spillover effects of three model regions: the Rheinisches Revier, Metropolis GZM, and Amsterdam Metropolitan Area. To identify the degree of integration of these regions in regional, national, and global value chains, the analysis uses a methodology that classifies economic links into direct and indirect effects. The findings indicate that the Rheinisches Revier is more closely linked with local suppliers of intermediate inputs, whereas the Metropolis GZM and Amsterdam Metropolitan Area have stronger connections with national and international suppliers. Notably, the Amsterdam Metropolitan Area exhibits a high foreign share, attributed to its robust international presence, particularly in service activities. The differences in economic interlinkages between the three regions are influenced by significant factors, namely geographical position and economic structure. The Rheinisches Revier and the Metropolis GZM have a larger manufacturing share, which includes the production of manufactured intermediate input goods, that contribute to regional gross value added (GVA). Conversely, the Amsterdam Metropolitan Area has a relatively small GVA income share because of its focus on service provision. Overall, this analysis highlights the importance of understanding the location and sectoral background of suppliers of intermediate inputs to determine the regional structure of upstream and downstream value chains.

This analysis delves into the spatial econometric impacts on employees and gross value added (GVA) resulting from recycling potentially eligible amounts of polyurethane (PU) hard foam in specific regions. Regional disaggregation is employed to estimate PU hard foam amounts, considering population and building density for refrigerator/freezer and building and construction PU hard foam, respectively. The Amsterdam Metropolitan Region exhibits the highest estimated PU hard foam amounts, primarily due to its larger population. Regional differences are pronounced, reflecting the diversity in waste streams. Electrical and electronic appliances contribute less to PU hard foam than building and construction, with varying lifespans affecting their significance.

Regarding the estimated effects on employment in the regions, the primary distinction between Germany and Poland is that in Germany, increases in PU hard foam are considered to lead to a net positive effect originating within a region. In contrast, in Poland, this effect appears to be influenced by neighboring regions, suggesting positive spillovers for Poland and negative spillovers for Germany. In Poland, the PU hard foam value stream seems to be less localized and more supra-regional than in Germany. In the Netherlands, the special role of the model region as the capital city might influence results. Results for potential impacts on employment (EMP) indicate a net negative effect. However, as this is dependent on changes in the amounts of PU hard foam in neighboring regions, a definitive implication should be approached with caution.

However, definitive implications are subject to the exact region and its neighbors. The temporal variance of PU hard foam availability after its end-of-life introduces uncertainty. Quality issues and the non-local nature of waste streams further compound this uncertainty. Still, the study provides valuable insights into the potential spatial econometric impacts of PU hard foam recycling on employment and GVA in different regions. However, future research can benefit from improved data availability, and therefore, this analysis marks only a start in investigating the recycling of end-of-life products.

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Disclaimer

Any dissemination of results must indicate that it reflects only the author's view and that the Agency and the European Commission are not responsible for any use that may be made of the information it contains.

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List of Abbreviations

GVA	Gross value added
GVC	Global value chains
IO	Input-Output
NUTS	Nomenclature of Territorial Units for Statistics
PU	Polyurethane (hard foam)
LU	Land use
TOTALPUWASTETONS	Estimated amount of total PU hard foam produced contained in refrigerators and insulation boards/sandwich panels
POPDENSPERKM2	Population density per square kilometer
DHHINC	Average household income
wTOTALPUWASTETONS	Estimated amount of total PU hard foam produced contained in refrigerators and insulation boards/sandwich panels – in neighboring regions (spatially weighted)
wPOPDENSPERKM2	Population density per square kilometer – in neighboring regions (spatially weighted)
wDHHINC	Average household income – in neighboring regions (spatially weighted)

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1 Introduction

We examine the economic connections and spillover effects of the Rheinisches Revier, Metropolis GZM, and the Amsterdam Metropolitan Area at the regional, national, and global levels, using a commonly used methodology in applied economic research. This approach helps us identify the level of integration of the three model regions in regional, national, and global value chains. Additionally, the impact that estimated waste streams have on regional employment and gross value added are investigated.

We can classify economic links into two types: direct and indirect effects. The direct effect is generated by producing final goods in the model regions, which creates demand for intermediate goods and inputs throughout the value chain. For example, the production of polyurethane hard foam requires various materials and services, leading to increased production in the supplier industries of the chemicals sector. These indirect effects can occur locally, nationally, and internationally due to interregional connections in production processes. Our analysis uses indirect effects to gauge the economic connections between the model region and other areas.

Spatial econometrics studies spatial aspects and data structures, addressing spatial dependence and heterogeneity (Anselin, 2010). It extends standard econometric methods by leveraging proximity for more precise regression results and involves categorizing observations into regions, like counties or census tracts (LeSage and Pace, 2009). Recognizing that true variable interactions extend beyond administrative borders, spatial econometrics explores regional interdependence. It emerged due to spatial dependence violating the assumption of independently distributed data, impacting regression results. Spatial econometrics can also be applied to all disciplines where regionalized data is present, which is why it is used here to account for possible interregional dependencies of PU hard foam waste streams.

The analyses executed in this deliverable can be separated into two main branches: First, regional economic interlinkages of the model regions on a national and international level are examined in section 2. Section 3 complements these analyses with spatial econometric estimations of the impact that the potential of recyclable PU hard foam relates to two major economic indicators: the number of employees and gross value added.

2 Regional economic interlinkages of the model regions

For our analysis in this section, we use the Nomenclature of Territorial Units for Statistics (NUTS) 2 level, which provides the most detailed data on interregional and intersectoral linkages. Specifically, we allocate each of the three model regions to a specific NUTS-2 region: Cologne and Dusseldorf for the Rheinisches Revier model region, Silesian Voivodeship for the Upper Silesia / Metropolis GZM model region, and North Holland for the Amsterdam Metropolitan Area.

In the following sections, we analyze the economic interlinkages of each model region in terms of gross value added (GVA). We organize our analysis as follows: First, we outline the interlinkages of the Rheinisches Revier, followed by a discussion of its national and international interlinkages and its role within global value chains. We then repeat this analysis for the Metropolis GZM and the Amsterdam Metropolitan Area.

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2.1 Rheinisches Revier

Using official data on the interregional flow of goods and services to calculate an economic direct and indirect impact factor for the Rheinisches Revier of about 1.8. This indicates that producing 1 million Euro of GVA in this region leads to a boost of about 0.8 million Euro of additional GVA effects across the upstream value chain worldwide. The subsequent sections provide an account of how this division occurs both nationally and internationally, along with an examination of how the Rheinisches Revier fits within the global value chains.

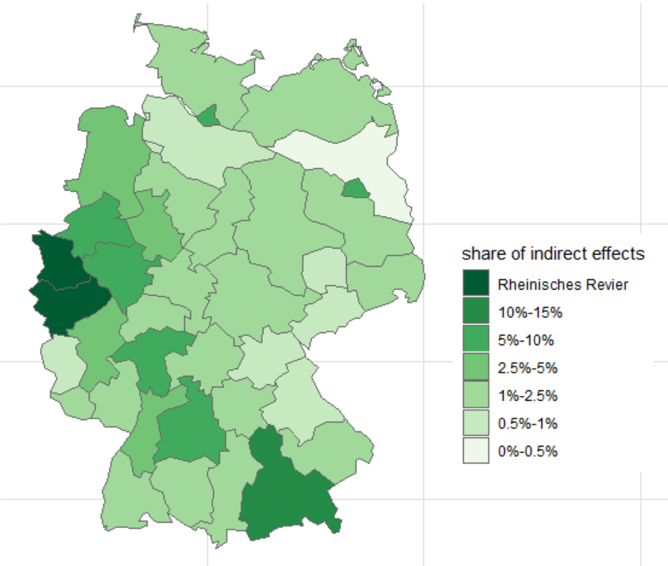
2.1.1 National regional interlinkages

The Rheinische Revier has a strong local value chain with a high degree of economic interlinkages. Figure 1 presents a measure of the extent of upstream interconnections of the Rheinisches Revier. Here, indirect effects denote the GVA produced in regions outside of the Rheinisches Revier in Germany by creating intermediate inputs that are eventually employed in the production procedures of industries and firms in the Rheinisches Revier, as highlighted in dark green in Figure 1.

In the Rheinisches Revier's upstream value chain in Germany, approximately 83% of the total GVA is generated by suppliers located in the administrative regions of Cologne and Dusseldorf. Of the model region's entire indirect GVA effects in Germany, roughly 47% originate from the Dusseldorf region, with the Cologne region contributing 36% of GVA.

However, neighboring regions also play a crucial role in creating intermediate input goods for the Rheinisches Revier, accounting for a considerable proportion (up to 7%) of the model region's total indirect GVA effects in Germany, excluding indirect effects within the Rheinisches Revier. The proximity of these regions helps to decrease transportation costs, and local public utilities, such as water and waste management, are usually utilized. Furthermore, suppliers of business services, such as financial and personnel services, maintenance, and repair, typically operate near their clients.

FIGURE 1: NATIONAL UPSTREAM INTERLINKAGES TO THE RHEINISCHES REVIER



SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX A

As depicted in Figure 1, the Rheinisches Revier has strong economic relationships with German regions outside of its immediate vicinity. Regions such as Darmstadt in Hessen, Stuttgart in Baden-

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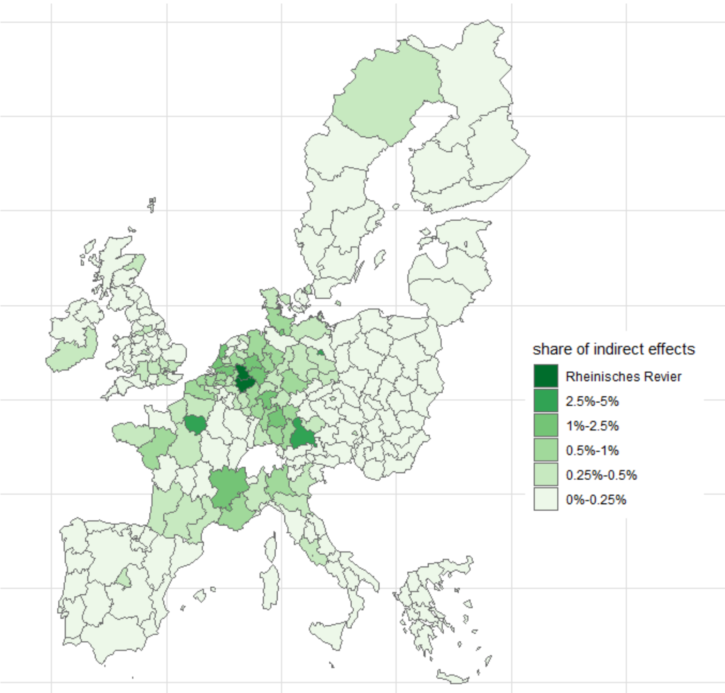
Württemberg, and Upper Bavaria in Bavaria, located in the south of Germany, also have significant economic interconnections with the Rheinisches Revier. For instance, Upper Bavaria contributes approximately 11% of the total indirect GVA effects of the model region in Germany, excluding the Rheinisches Revier. Additionally, industries and companies in the northern cities of Hamburg and Berlin have stronger economic ties to the model region than the average. Nonetheless, regions located in the east of Germany are not generally closely connected to the Rheinisches Revier in terms of supply chains.

2.1.2 International interlinkages

Figure 2 depicts the European upstream interconnections to the Rheinisches Revier (interpreted in the same way as Figure 1). The Rheinisches Revier has strong economic ties with neighboring countries, such as the Netherlands, Belgium, and France, from a European perspective. For instance, approximately 3% of the total global indirect GVA effects resulting from the Rheinisches Revier's economic activities outside of the model region can be credited to the production of intermediate inputs in the French administrative region of Île-de-France. Furthermore, businesses in northern Italy and the United Kingdom benefit from economic activities in the Rheinisches Revier, with a potential 1% share in the total GVA generated within the supply chains of the Rheinisches Revier. Nevertheless, other Mediterranean and East European regions, such as the Baltic states, have lower shares in total indirect GVA effects. The upstream value chains of companies operating in the Rheinisches Revier demonstrate a clear economic emphasis on suppliers in the southwestern regions of Europe, as highlighted in Figure 2.

FIGURE 2: EUROPEAN UPSTREAM INTERLINKAGES TO THE RHEINISCHES REVIER



SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX A

On a global perspective, the economic activities in the Rheinisches Revier exhibit relatively strong economic connections with the United States and China. Roughly 8% of the total GVA in the upstream value chains of the model region's industries is generated in the US, while the GVA proportion of companies located in China constitutes approximately 5% of the total indirect effects of the Rheinisches

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Revier, excluding the indirect effects within the model region itself. The non-European share in the total indirect effects of the Rheinisches Revier outside of the model region is roughly 30% in general.

2.1.3 (Global) Value chains

The economic interconnections of the Rheinisches Revier can be classified into direct and indirect effects, further divided into a domestic, regional, and foreign share. The domestic or local share in total GVA effects amounts to approximately 81%, while the regional and foreign shares only account for 5% and 14%, respectively. This suggests that the Rheinisches Revier exhibits a high degree of local embeddedness.

Apart from its economic integration in upstream value chains, the Rheinisches Revier's ties with globally operating companies can also be analyzed from a downstream perspective. The region is incorporated into global value chains itself in terms of intermediate input production and the provision of services that are ultimately embodied in manufactured final products in other regions and countries. Consequently, using the global value chain (GVC) income approach, the total GVA in the Rheinisches Revier can be separated into two components: value added produced in activities that contribute to global value chains (GVC income) and value added generated in activities that do not contribute to GVCs. Our analysis shows that the Rheinisches Revier's GVC income accounts for approximately 25% of the total regional GVA, marginally higher than the GVC income to total GVA ratio at the national level (24%). Thus, the Rheinisches Revier is embedded into downstream global value chains to a similar degree as Germany as a whole.

2.2 Metropolis GZM

Utilizing the same methodology as in the preceding sections, we compute an economic direct and indirect impact factor for the Metropolis GZM at roughly 2.2. This implies that generating 1 million Euro of GVA in this model region triggers supplementary GVA effects along its upstream value chain of approximately 1.2 million Euro on a global scale. The subsequent sections outline how this is distributed nationally and internationally and also analyze how the Metropolis GZM is positioned in global value chains.

2.2.1 National regional interlinkages

Figure 3 illustrates the national upstream interconnections to the Metropolis GZM, serving as an indicator of its degree of upstream interconnections. As outlined previously, indirect effects denote the GVA produced in Polish regions other than the Metropolis GZM by creating intermediate inputs that are eventually utilized in the production processes of industries and companies in the model region (represented in dark green). As anticipated, the Metropolis GZM region exhibits the most robust economic connections with the local economy. Assessing the region's proportion in total indirect GVA effects reveals that suppliers situated in the domestic Silesian Voivodeship constitute approximately 76% of the total GVA generated in the upstream value chain of the Metropolis GZM in Poland.

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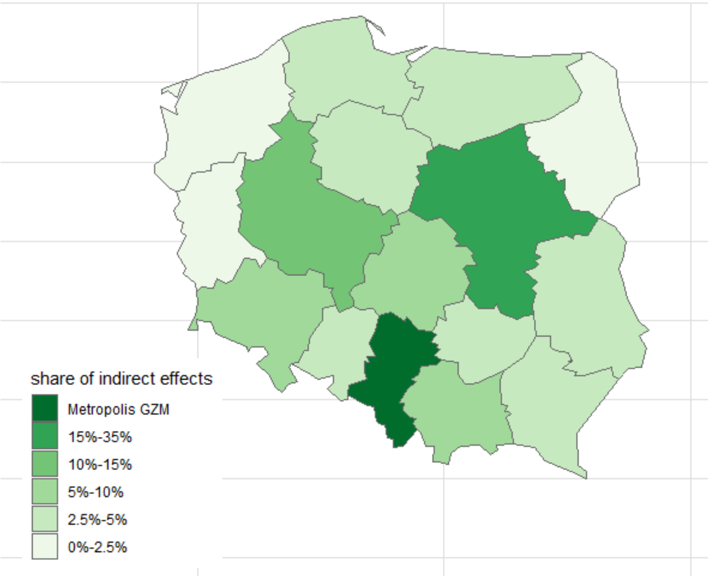
FIGURE 3: NATIONAL UPSTREAM INTERLINKAGES TO THE METROPOLIS GZM



SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX A

Apart from this, this model region demonstrates strong economic interconnections with other Polish regions, particularly with the Masovian Voivodeship situated to the north-west from the model region's viewpoint, as presented in Figure 3. This region with the Polish capital city, Warsaw, accounts for about 31% of the total indirect GVA effects of the Metropolis GZM in Poland, excluding the Silesian Voivodeship.

The production of intermediate inputs in the Greater Poland Voivodeship emerges as the second most important region, accounting for about 11% of the total indirect GVA effects of the Metropolis GZM in other Polish regions, creating a massive gap. It is worth noting that neither Voivodeship shares a direct border with the Metropolis GZM. Additionally, the Lower Silesian province, having the third-highest degree of economic interconnections with the Metropolis GZM, also lacks a common border with the Silesian region (as illustrated in Figure 3).

Nevertheless, the neighboring regions of the GZM, Lesser Poland, and Łódź located at the northern and western boundaries of the Metropolis GZM, respectively, perform a significant role in creating intermediate input goods for the model region. Specifically, the Lesser Poland and Łódź Voivodeships contribute approximately 9% and 8%, respectively, in total indirect GVA effects outside the Metropolis GZM (as shown in Figure 3). This supports the hypothesis of the high significance of local value chains in reducing transportation costs, among other factors, as mentioned in previous sections. However, regions situated in the northeast and northwest of Poland exhibit a weaker link with the Metropolis GZM in terms of supply chains.

2.2.2 International interlinkages

As depicted in Figure 4, the Metropolis GZM region exhibits strong economic ties with the neighboring country, Czech Republic, in the southwest. This figure follows the same interpretation as the previous ones. Each Czech region on NUTS-2 level contributes to the international indirect GVA effects of the Metropolis GZM outside the model region in the range of 0.5% to 1.5%. The production of intermediate inputs in the Czech economy accounts for approximately 7% of total global indirect GVA effects resulting from the economic activities of the Metropolis GZM. In addition, businesses in the south and (north)west of Germany, including suppliers in the Rheinisches Revier, benefit from the economic

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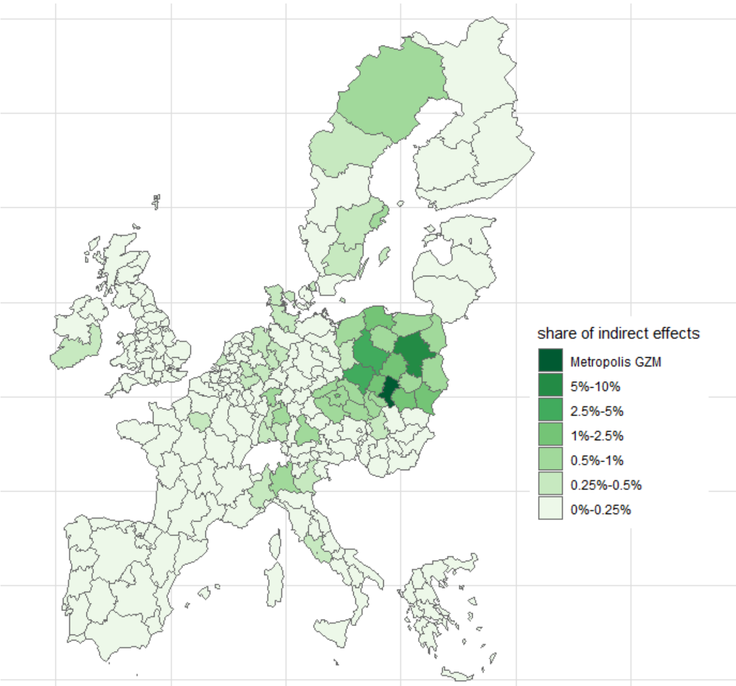
activities in the Metropolis GZM, with up to a 1% share in the total GVA generated within the upstream supply chains of the Metropolis GZM.

Furthermore, Italian regions in the north and middle, as well as Danish regions, exhibit remarkable interconnections with the Metropolis GZM. Figure 4 illustrates that Swedish regions rank among those with the highest degree of economic interlinkages to the Metropolis GZM outside Poland, with a share of 3% in total indirect GVA effects of the model region outside the Metropolis GZM.

However, regions in the UK, France, and Spain, as well as the Baltic States, do not demonstrate strong economic connections with the Metropolis GZM in terms of the production of intermediate inputs. Instead, the upstream value chains of companies operating in the Metropolis GZM reveal a comprehensive economic focus on suppliers in other Polish regions and the Czech Republic, as mentioned earlier. Approximately 32% of the total indirect GVA effects outside the Metropolis GZM are attributed to both countries.

Globally, the economic activities in the Metropolis GZM demonstrate strong economic linkages with China, as companies located in China contribute approximately 10% of the total indirect effects of the Metropolis GZM. On the other hand, the economic connections with US suppliers are comparatively lower, accounting for around 6% of total indirect GVA effects outside of the model region.

FIGURE 4: EUROPEAN UPSTREAM INTERLINKAGES TO THE METROPOLIS GZM



SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX A

2.2.3 (Global) Value chains

The economic interlinkages of the Metropolis GZM can be divided into direct and indirect effects, and can be further categorized into a domestic, regional, and foreign share. The domestic or local share in total GVA effects accounts for around 70%, while the regional and foreign shares account for 8% and 22%, respectively. This suggests a high degree of local embeddedness of the Metropolis GZM.

In addition to analyzing the model region's economic interlinkages from an upstream perspective, its linkages with globally operating companies can also be studied from a downstream perspective using the GVC income approach, as discussed in more detail for the Rheinisches Revier section. According to

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our analysis, the GVC income of the Metropolis GZM amounts to around 25% of the total regional GVA. This implies that approximately one-fourth of the GVA generated in the model region is linked to the production of intermediate input goods and the provision of services that eventually become part of the manufactured final products in other regions and countries. Interestingly, the model region's GVC income share is slightly larger than the national ratio between GVC income and total GVA (23%).

2.3 Amsterdam Metropolitan Area

Using official statistics on the interregional flow of goods and services, we have calculated an economic direct and indirect impact factor for the Amsterdam Metropolitan Area of around 2.0. This means that generating 1 million Euro of GVA in this model region stimulates additional GVA effects along its upstream value chain worldwide in the same amount. In the following sections, we will detail how the indirect GVA effects are split up nationally and internationally and also discuss how the Amsterdam Metropolitan Area fits into global value chains.

2.3.1 National regional interlinkages

We calculate that around 64% of the model region’s total indirect GVA effects in the Netherlands are generated in the region North Holland representing the Amsterdam Metropolitan Area. The Amsterdam Metropolitan Area has therefore the strongest economic interlinkages with its own local economy. This is shown in Figure 5 which gives an indicator of the degree of upstream interlinkages of the Amsterdam Metropolitan Area. As in previous sections, this highlights the indirect effects refer to the GVA generated in Dutch regions others than Amsterdam Metropolitan Area by producing intermediate inputs that are finally used in the production processes of industries and companies in the model region (marked in dark green).

When we disregard the local effects and focus on national spillover effects of the Amsterdam Metropolitan Area, we find that the province of South Holland is the most relevant region when it comes to providing intermediate inputs for the area. Suppliers in South Holland account for over 27% of the total indirect GVA effects of the Amsterdam Metropolitan Area in the Netherlands, outside of the model region. This is in line with the economic intuition of strong interlinkages between neighboring regions due to factors such as small transportation and transaction costs.

Another region that accounts for a significant share in the total indirect GVA effects of the Amsterdam Metropolitan Area on a national level is the province of North Brabant, located in the south of the Netherlands. Suppliers in this region are responsible for about 22% of the total GVA generated in the upstream value chain of the Amsterdam Metropolitan Area in other Dutch regions.

However, the Amsterdam Metropolitan Area is not intensively linked with Dutch regions in the east and north of the Netherlands, including the immediate neighboring provinces of Flevoland and Friesland, which have a GVA share of 3% and 5%, respectively.

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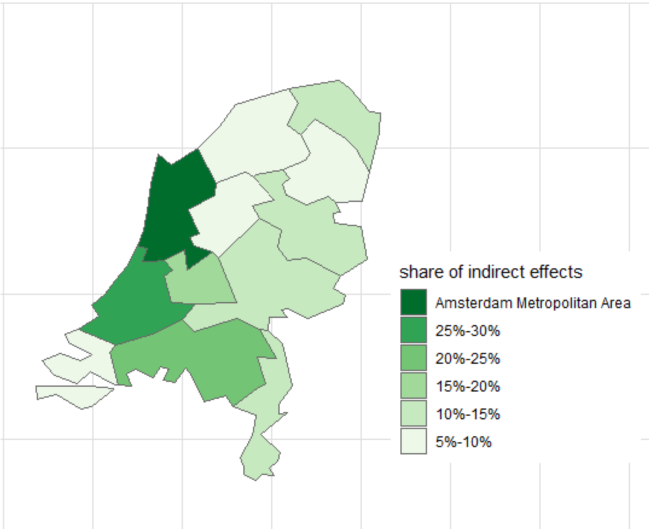
FIGURE 5: NATIONAL UPSTREAM INTERLINKAGES TO THE AMSTERDAM METROPOLITAN AREA



SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX A

2.3.2 International interlinkages

Figure 6 provides an overview of the European upstream interlinkages to the Amsterdam Metropolitan Area. The figure shows that the region has strong economic connections with German regions, not only in the west but also in the south. Abound 16% of global indirect GVA effects of the Amsterdam Metropolitan Area outside of the model region are generated by suppliers in Germany, with the regions Dusseldorf and Cologne representing the Rheinisches Revier being among the most relevant regions due to their proximity to the model region. Additionally, each of the southern regions of Darmstadt, Stuttgart, and Upper Bavaria accounts for about 1% in total indirect GVA effects worldwide outside of the model region.

Furthermore, the Amsterdam Metropolitan Area has economic interlinkages with regions in the UK, particularly at the southeast coast, with Inner London accounting for about 1% of total indirect GVA effects of the model region. In contrast, only a few regions in France economically benefit from the Amsterdam Metropolitan Area by supplying intermediate inputs, with the metropolitan area Île-de-France (including Paris) accounting for about 1% of total GVA effects of the Amsterdam Metropolitan Area outside of the model region.

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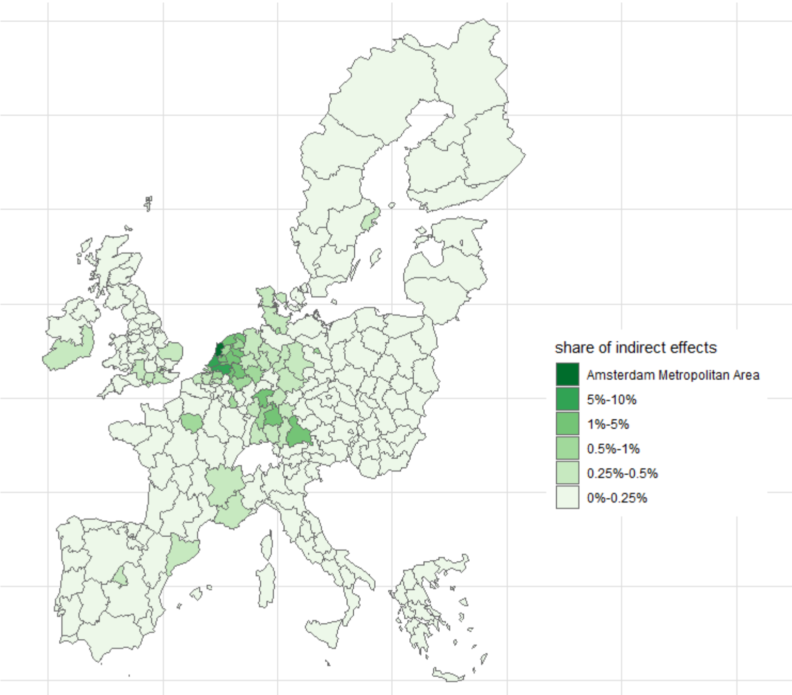
FIGURE 6: EUROPEAN UPSTREAM INTERLINKAGES TO THE AMSTERDAM METROPOLITAN AREA



SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX A

In general, the Amsterdam Metropolitan Area is characterized by strong economic interlinkages with other European urban agglomerations, while regions in Eastern and Southern Europe, as well as the Scandinavian and Baltic States, do not have significant economic connections with the Amsterdam Metropolitan Area in terms of the production of intermediate inputs.

From a global perspective, the economic activities in the Amsterdam Metropolitan Area are highly linked with the United States. Approximately 10% of the total GVA in the upstream value chains of the model region's industries is generated in the US. This is a significant share compared to Chinese suppliers, which have lower economic connections with the Amsterdam Metropolitan Area, amounting to around 4% of total indirect GVA effects outside of the model region.

2.3.3 (Global) Value chains

This section outlines how the economic interlinkages of the Amsterdam Metropolitan Area can be broken down into a domestic, regional (national), and foreign share. The domestic or local share in total GVA effects amounts to around 66%, while the regional and foreign shares account for 9% and 25%, respectively. This suggests that the Amsterdam Metropolitan Area is highly integrated into international value chains, with a strong demand for intermediate consumption. One possible explanation for this is that the area is dominated by Amsterdam, which has a strong international focus, and also due to its economic interlinkages with other international metropolitan areas like London and Paris, particularly in the field of business and financial services.

However, when looking at the downstream perspective of the flow of goods using the GVC income approach, the GVC income of the Amsterdam Metropolitan Area only accounts for around 18% of the total regional GVA, which is equal to the national average of GVC income share. This indicates that the model region's economic linkages in the global value chain are not as strong in terms of the flow of goods.

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2.4 Comparison of the model regions and conclusion

This section examines the differences in the economic interlinkages of the three model regions: the Metropolis GZM, the Amsterdam Metropolitan Area, and the Rheinisches Revier. Figure 7 provides a summary of the structure of these interregional linkages.

Compared to the other two regions, the Rheinisches Revier is more closely linked with local suppliers for intermediate inputs. In terms of the breakdown of economic interlinkages into a domestic, regional, and foreign share, companies in the Rheinisches Revier are responsible for about 81% of the total GVA effects generated by this model region. This is in contrast to the Metropolis GZM and Amsterdam Metropolitan Area, where the domestic shares only account for 70% and 66%, respectively.

Additionally, the Rheinisches Revier has stronger interregional linkages with neighboring regions, whereas the neighboring regions of the Metropolis GZM and Amsterdam Metropolitan Area only partially contribute to the production of intermediate input goods for these model regions. In contrast, both the Metropolis GZM and Amsterdam Metropolitan Area are more strongly embedded in national and international value chains than the Rheinisches Revier.

The Rheinisches Revier has a national and foreign share of 19% (5%+14%), while the Metropolis GZM has a share of 30% (8%+22%). However, the Amsterdam Metropolitan Area surpasses both with a share of 34% (9%+25%). The reason for the Amsterdam area's high foreign share could be due to the strong international presence of its capital city, Amsterdam. The city has strong connections with other metropolitan areas in the world, such as Paris and London, especially in terms of service activities, which may explain its high upstream economic interlinkages.

The Rheinisches Revier is more intensively linked with local suppliers, while the Metropolis GZM and Amsterdam Metropolitan Area have stronger links with national and international suppliers. However, there are similarities between the Amsterdam Metropolitan Area and the Rheinisches Revier in terms of their interregional linkages with German and Dutch regions. This can be explained by their geographical proximity to the German-Dutch border, which facilitates low transport costs and concentrated value chains. The Metropolis GZM also benefits from its proximity to the Czech Republic as a neighboring supplier.

From the downstream perspective of interregional flow of goods, the Rheinisches Revier and the Metropolis GZM are embedded into global value chains to roughly the same extent, with around 25% of total regional GVA related to the production of intermediate input goods and provision of services that are ultimately embodied in manufactured final products in other regions and countries. In contrast, the Amsterdam Metropolitan Area has a relatively small GVC income share of only 18%, which can be explained by its focus on the provision of services, especially real estate, renting and business activities, and non-market services for final use that do not contribute to GVC income. The Metropolis GZM and the Rheinisches Revier have a larger manufacturing share, including the production of manufactured intermediate input goods, which are used in the production processes of manufactured final goods in other countries and regions and thus contribute to regional GVC income.

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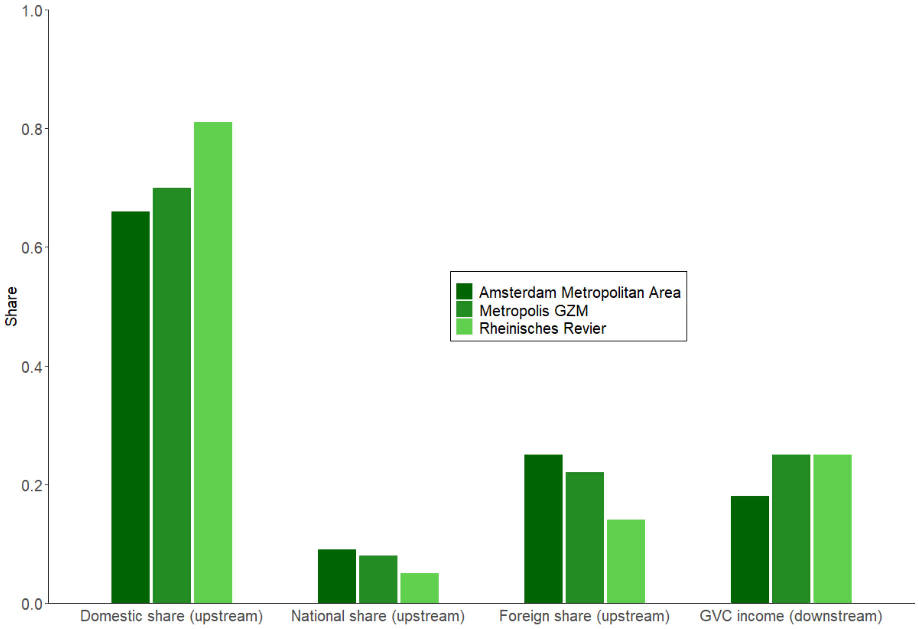
FIGURE 7: COMPARISON OF THE MODEL REGIONS REGARDING THE STRUCTURE OF ECONOMIC INTERLINKAGES



SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX A & B

In summary, the differences in the economic interlinkages between the three model regions are largely influenced by two factors: their geographical position and their economic structure, which includes the regional concentration of specific industrial activities. These factors determine the location and sectoral background of the suppliers of intermediate inputs and therefore the regional structure of the model region's upstream and downstream value chains.

3 Regional econometric impact estimation

3.1 Preliminary remarks and assumptions

In this section for our analysis, we use the NUTS 3-level regions to investigate the spatial econometric impacts on employees and gross value added in a region resulting from recycling potentially eligible amounts of PU hard foam related to amounts of PU hard foam. The following regions are used: Düren, Euskirchen, Heinsberg, Rhein-Erft-Kreis, Rhein-Kreis Neuss, Städteregion Aachen, and Mönchengladbach for Rheinisches Revier, Katowicki, Bytomski, Gliwicki, Sosnowiecki, and Tyski for Metropolis GZM and Greater Amsterdam for Amsterdam Metropolitan Area.

Categories used for refrigerator/freezer PU hard foam are approximated using data for electrical and electronic equipment, which includes mainly heat exchangers, particularly cooling appliances. For estimating PU from insulation boards/sandwich panels, data for building and construction PU hard foam is used (Conversio Market & Strategy GmbH, 2018).

In the first step, amounts of PU hard foam produced from refrigerators, freezers, and PU hard foam used in the building and construction sector (further referred to as PU hard foam for sandwich panels and insulation boards) are estimated on a regional level. Production data, available yearly, is extrapolated for 2000-2019 and regionally disaggregated according to the calculations in Appendix C. The base assumption for the disaggregation of produced PU relies for refrigerator PU hard form on the population in a region, as the determining geographical factor where a product is used and, after end-of-life, fed into the waste cycle, are mainly population. Where the population is higher, larger numbers of

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refrigerators are assumed; thus, a higher potential for PU hard foam can be available for recycling. Still, there is a high discrepancy between sold fridges and the number of fridges collected by waste management companies, so there is a high variance in the number of actually available PU stemming from these products.

For building and construction PU hard foam, the regional disaggregation is based on the building density in a region, where a higher density corresponds to more PU hard foam used and, after end-of-life, given into the waste stream. It has to be noted that the lifetime of an average refrigerator can be assumed to range from 10-15 years, and PU rigid foam building insulation can achieve a durability of around 50 years. Still, due to other building parts that could require earlier deconstruction of a building as their durability might be shorter, this value is also subject to high uncertainty. Although the values for panel/board PU hard foam are higher than for refrigerators/freezers, the lifetime for the former is considerably longer; thus, we use the aggregate for the estimations.

Checking the variables for spatial dependence proves the need for a spatial econometric approach. Together with control variables and a spatial weighting matrix, the values are log-transformed and estimated in a spatial Durbin error model, which includes additional spatially lagged regressors to account for interregional economic effects and a spatially lagged error term to model spatial dependence among regions explicitly. This is necessary because of the data exhibiting spatial autocorrelation and the concept of the waste streams of PU hard foam that are not only local but also interregional and transcend administrative borders. The model is estimated for the whole country at once, but effects for the model regions can be derived accordingly. Still, the estimated coefficients are average effects that hold for all regions. However, depending on the individual region's value of the variables, the outcome of a change is different in height. The following subsections focus on the estimations of PU hard foam for the model regions and then elaborate on the effects related to PU hard foam production and, by assumption, future eligible PU hard foam for recycling.

To account for some degree of variability in the potentially available amounts of PU hard foam for recycling in a region, we executed sensitivity tests applying a range of +/-10% of regionally disaggregated PU products, but values proved to be robust, which is why the following estimations show only the average, middle, case.

The estimated numbers are subject to uncertainty due to a lack of information on the actual regional distribution of PU products. The resulting estimated effects further underlie a highly uncertain time lag that needs to be considered when deriving implications from the results. Therefore, the results from the spatial econometric model show only a direction of influence, which would need to be confirmed by further studies containing more extended time series. Further information about estimation and data is listed in Appendix C & D.

3.2 Rheinisches Revier

3.2.1 Estimation of PU hard foam potential

In the Rheinisches Revier 2019, the estimated regionally disaggregated PU production is relatively high compared to the rest of Germany. With Euskirchen, Düren, and Rhein-Kreis Neuss, three regions falling into the highest quantile belong to the model region. Slightly lower amounts are in Städteregion Aachen, Heinsberg, and Rhein-Erft-Kreis. The lowest amounts in the Rheinisches Revier are estimated for Mönchengladbach. The numbers are mainly driven by PU hard foam from panels. However, when looking at the estimates separately (see Appendix C), differences between Städteregion Aachen, Düren, and Rhein-Erft-Kreis are not significant anymore.

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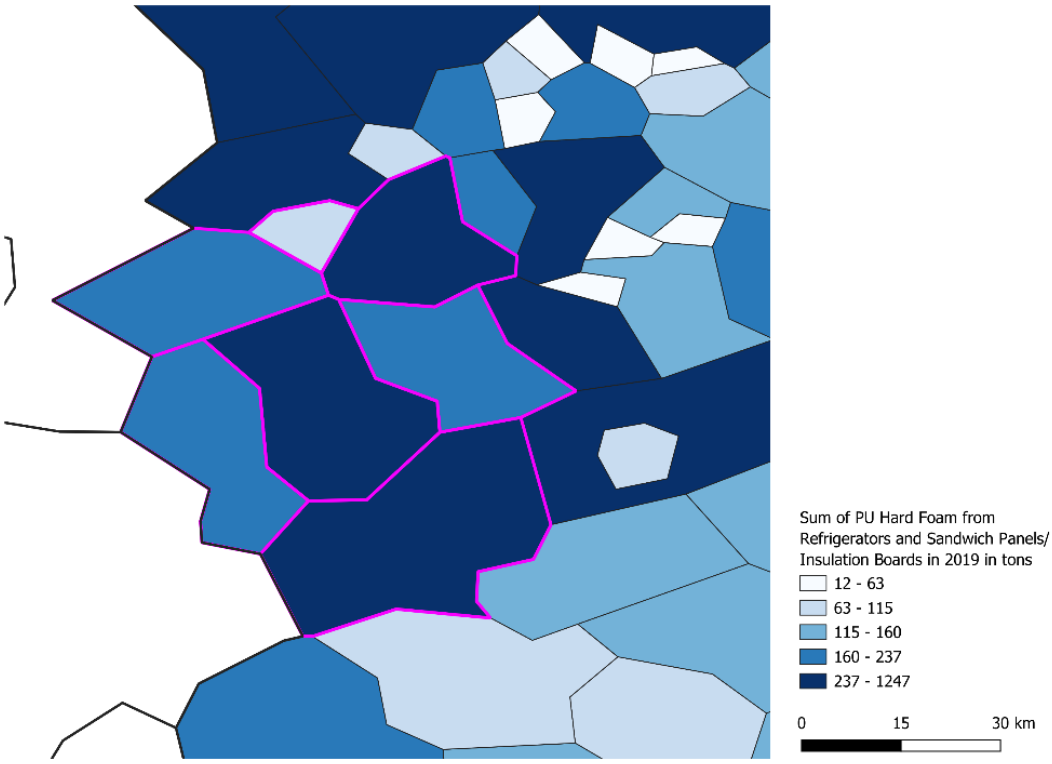
FIGURE 8: ESTIMATED AMOUNT OF TOTAL PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS IN 2019.



SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX C

3.2.2 Economic impacts of polyurethane hard foam potential

Table 1 shows the results from the spatial Durbin error model executing a regression of the mentioned variables on the number of employees. Included are effects from the total regionally assigned amount of PU hard foam from refrigerators and panels/boards, population, and average household income for the region under consideration and the neighboring regions (variables with a leading “w”). The results for TOTALPUWASTETONS are highly significant and positive, meaning if there is an increase of 1% in the variable in a region, EMP is assumed to react positively with an increase of 0.14%. An additional effect from increases of 1% in neighboring regions is supposedly negatively influencing employment in this region, thus illustrating a slight negative local spillover. Overall, as the effect is small, there is a positive net effect to be assumed. Also, λ indicates a relatively high positive effect due to regional dependence in the relation between PU hard foam production amounts and employment, confirming the importance of a regional-focused approach.

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TABLE 1: ESTIMATED IMPACTS OF TOTAL PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS ON EMPLOYMENT IN GERMANY ON NUTS 3 LEVEL.

EMP	Estimate	Std. Error	t-value	Pr(>|t|)	
TOTALPUWASTETONS	0.1424326	0.0332261	4.2868	1.81E-05	***
POPDENSPERKM2	0.1787815	0.0085649	20.8736	< 2.2e-16	***
DHHINC	0.4027543	0.019805	20.336	< 2.2e-16	***
wTOTALPUWASTETONS	-0.0663097	0.035433	-1.8714	0.06129	.
wPOPDENSPERKM2	-0.0261741	0.0108697	-2.408	0.01604	*
wDHHINC	-0.1786837	0.0259435	-6.8874	5.68E-12	***
λ	0.310533	0.014476	21.451	< 2.2e-16	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX C & D

The model substituting employment with GVA in Table 2 shows larger anticipated effects, indicating an increase of 0.36% in regional GVA from a 1% increase in the amount of PU hard foam in a region and an additional increase drawing from PU in neighboring regions. The effects are highly significant, supporting the indication of the importance of the value stream of PU hard foam from refrigerators to GVA.

TABLE 2: ESTIMATED IMPACTS OF TOTAL PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS ON GROSS VALUE ADDED IN GERMANY ON NUTS 3 LEVEL.

GVA	Estimate	Std. Error	t-value	Pr(>|t|)	
TOTALPUWASTETONS	0.355308	0.036882	9.6336	< 2.2e-16	***
DHHINC	0.640686	0.031995	20.0246	< 2.2e-16	***
wTOTALPUWASTETONS	0.197071	0.040105	4.9138	8.93E-07	***
wPOPDENSPERKM2	-0.107643	0.015099	-7.1292	1.01E-12	***
wDHHINC	-0.106071	0.040611	-2.6119	0.009005	**
λ	0.236423	0.015081	15.677	< 2.2e-16	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX C & D

Together with the results from the amounts estimated of PU production in the model region, higher effects are anticipated for the regions where the value for TOTALPUWASTETONS is relatively higher. This would apply to Euskirchen, Düren, and Rhein-Kreis Neuss.

3.3 Metropolis GZM

3.3.1 Estimation of PU hard foam potential

Metropolis GZM exhibits relatively lower estimates of PU hard foam production than all regions in Poland. The estimated amounts are lower than the average, especially in Gliwicki, Katowicki, and Tyski. This distribution is also mirrored for the building and construction sector PU hard foam. However, when looking at the estimates for electrical and electronic appliances, the regions Sosnowiecki and Katowicki are in the highest quantile. The role of the latter PU hard foam product seems to be relatively more relevant to these regions compared to PU used in building and construction. However, the numbers for this division are, on average, much higher.

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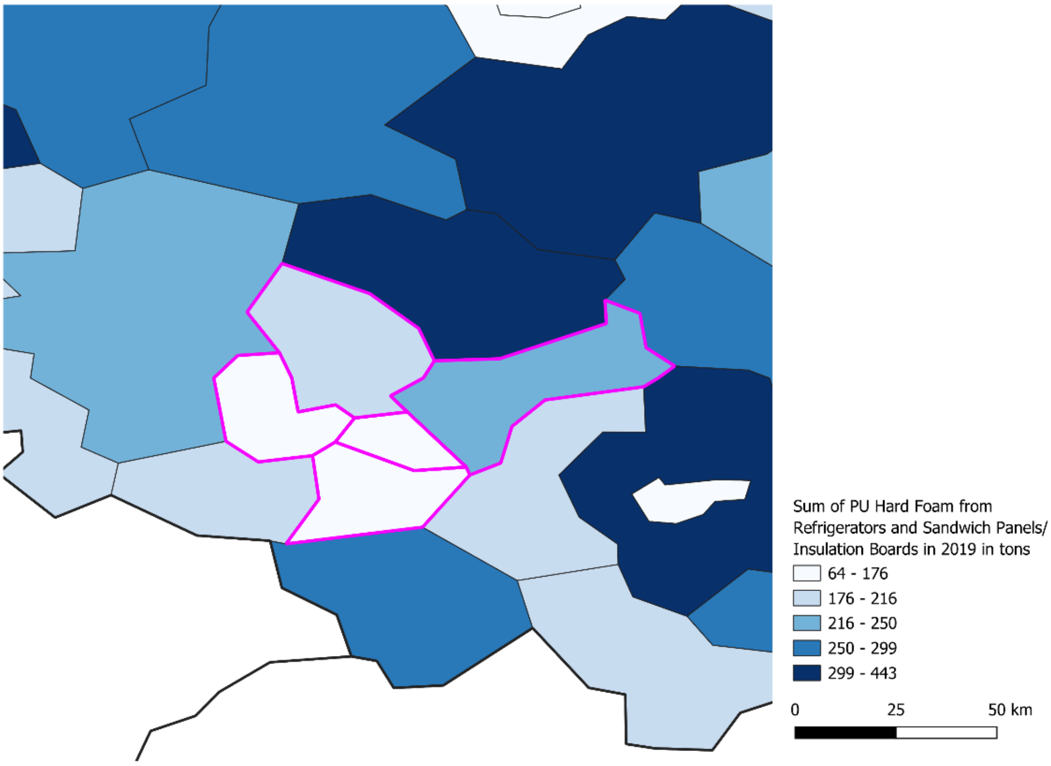
FIGURE 9: ESTIMATED AMOUNT OF TOTAL PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS IN 2019.



SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX C

3.3.2 Economic impacts of polyurethane hard foam potential

The estimated effects of TOTALPUWASTETONS on EMP in Poland within a region are negative, meaning that if in a region, a 1% increase of TOTALPUWASTETONS is related to a decline of -2.7% in EMP. In contrast, the effect on EMP from neighboring regions increasing wTOTALPUWASTETONS by 1% is positive and highly significant with 3.4%. The net effect is thus positive. Depending on their neighboring regions, Bytomski and Sosnowiecki are likely to benefit more from that effect, as they are located to a Northern neighbor with a high value of estimated TOTALPUWASTETONS.

TABLE 3: ESTIMATED IMPACTS OF TOTAL PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS ON EMPLOYMENT IN POLAND ON NUTS 3 LEVEL.

EMP	Estimate	Std. Error	t-value	Pr(>|t|)	
TOTALPUWASTE-TONS	-2.66934	0.82792	-3.2242	0.001263	**
POPDENSPERKM2	2.11564	0.31262	6.7673	1.31E-11	***
wTOTALPUWASTE-TONS	3.36626	0.82875	4.0619	4.87E-05	***
wPOPDENSPERKM2	-0.93243	0.32357	-2.8817	0.003955	**
λ	0.366421	0.044595	8.2167	< 2.2e-16	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX C & D

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Regarding the model results related to GVA, the estimated effects are slightly smaller, and the driver stems from within the region. Although the net effect resulting from an increase in TOTALPUWASTETONS and wTOTALPUWASTETONS by 1% is small (1.5% and -1.4% respectively), it is positive and significant.

TABLE 4: ESTIMATED IMPACTS OF TOTAL PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS ON GROSS VALUE ADDED IN POLAND ON NUTS 3 LEVEL.

GVA	Estimate	Std. Error	t-value	Pr(>|t|)	
TOTALPUWASTETONS	1.531089	0.149471	10.2434	< 2.2e-16	***
POPDENSPERKM2	0.329243	0.059379	5.5448	2.94E-08	***
DHHINC	0.633678	0.075215	8.4248	< 2.2e-16	***
wTOTALPUWASTETONS	-1.353237	0.15009	-9.0162	< 2.2e-16	***
wPOPDENSPERKM2	0.116851	0.06287	1.8586	0.06308	.
wDHHINC	0.359516	0.080617	4.4595	8.21E-06	***
λ	0.52116	0.02729	19.097	< 2.2e-16	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX C & D

3.4 Amsterdam Metropolitan Area

3.4.1 Estimation of PU hard foam potential

The estimated PU hard foam potential in the model region is assumed to be in the higher quantiles for the sum of electrical and electronic appliances and building and construction used PU hard foam. As for the other regions, this is mainly driven by the latter category, but compared to other regions in the country, the region exhibits the highest values concerning the former category. The region seems to stand alone compared to neighboring regions, exhibiting relatively different potentials, which might be due to the importance of the model region for the country, which also contains the capital city, Amsterdam.

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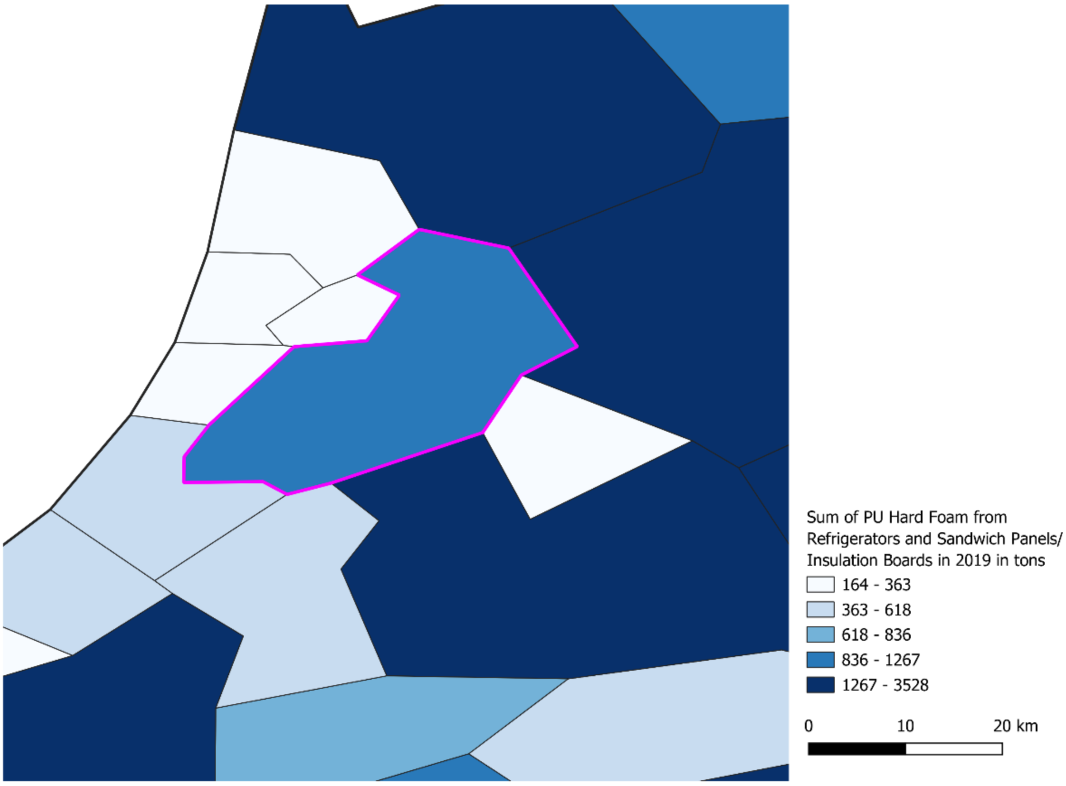
FIGURE 10: ESTIMATED AMOUNT OF TOTAL PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS IN 2019.



SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX C

3.4.2 Economic impacts of polyurethane hard foam potential

In the Netherlands, the impacts estimated on EMP in the model in Table 5 are stemming mainly from within the region, as a 1% increase in TOTALPUWASTETONS is related to a 0.5% increase in EMP and a 1% increase in a neighboring region is related with -0.6%. In contrast to the other countries, the net effect is assumed to be negative. Effects are highly significant, but as the regions surrounding the model region exhibit either larger or considerably lower assigned values of TOTALPUWASTETONS, the actual net effect might not lead to a negative overall outcome. This can be related particularly in the case of changes in PU hard foam from electrical and electronic appliances, as the absolute value for the model region is considerably higher than for neighboring regions.

TABLE 5: ESTIMATED IMPACTS OF TOTAL PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS ON EMPLOYMENT IN THE NETHERLANDS ON NUTS 3 LEVEL.

EMP	Estimate	Std. Error	t-value	Pr(>|t|)	
TOTALPUWASTETONS	0.4700752	0.1020092	4.6082	4.06E-06	***
POPDENSPERKM2	-0.0371223	0.0092904	-3.9958	6.45E-05	***
DHHINC	0.4931628	0.0579938	8.5037	< 2.2e-16	***
wTOTALPUWASTETONS	-0.562427	0.103093	-5.4555	4.88E-08	***
wPOPDENSPERKM2	-0.0798758	0.0182973	-4.3654	1.27E-05	***
λ	0.309516	0.043772	7.0711	1.54E-12	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX C & D

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The effects in Table 6 show that a 1% increase in TOTALPUWASTETONS can be related to a 1.4% increase within the region and a -1.3% effect counteracting from neighboring regions. The overall effect on GVA is positive, and the magnitude is also higher than that of effects related to EMP.

TABLE 6: ESTIMATED IMPACTS OF TOTAL PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS ON GROSS VALUE ADDED IN THE NETHERLANDS ON NUTS 3 LEVEL.

GVA	Estimate	Std. Error	t-value	Pr(>|t|)	
TOTALPUWASTETONS	1.434425	0.154867	9.2623	< 2.2e-16	***
POPDENSPERKM2	-0.045687	0.014607	-3.1279	0.001761	**
DHHINC	0.840873	0.098971	8.4961	< 2.2e-16	***
wTOTALPUWASTETONS	-1.31333	0.15742	-8.3428	< 2.2e-16	***
wPOPDENSPERKM2	-0.090207	0.030174	-2.9896	0.002793	**
λ	0.437262	0.039218	11.15	< 2.2e-16	***

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1.

SOURCE: BASED ON AUTHOR CALCULATIONS AS OUTLINED IN APPENDIX C & D

3.5 Comparison of the model regions and conclusion

Comparing the estimated amounts of PU hard foam among the three model regions, the Amsterdam Metropolitan Region is estimated to have the highest amounts due to the disaggregation, mainly due to the region having the largest population. Lowest values are found for, e.g., Mönchengladbach, Tyski, Katowicki (TOTALPUWASTETONS), Euskirchen, Düren/Mönchengladbach, and Heinsberg (FRIDGEPUTONS) and Katowicki, Gliwicki, and Mönchengladbach (PANELPUTONS), which shows the high regional diversity of the model regions not only nationally, but also internationally (compare Appendix C).

The differences are also mirrored in the two components that make up the total sum of PU hard foam relevant for the project, electrical and electronical appliances and building and construction PU hard foam. With amounts from the former category being much lower than the estimated amounts for the building and construction sector, the respective lifespans of the products might be assumed to counteract the relevance of the effects. Heat exchangers need to be replaced more often so that small, but often increases in these PU hard foam categories might compensate higher absolute effects of the panels and boards with considerably longer lifespans.

With regard to the estimated effects on employment in the regions, the main difference between Germany and Poland seems to be that in Germany, increases in PU hard foam considered lead to a net positive effect which results from within a region, whereas in Poland it seems to be due to neighboring regions. This indicates negative spillovers for Germany and positive spillovers for Poland. In Poland, PU hard foam as a value stream seems to be less local and more supra-regional than in Germany. In the Netherlands, the model region’s special role as capital city might influence results. Results for possible impacts on EMP are indicating a net negative effect, but as this is dependent on the changes of the amounts of PU hard form in neighboring regions, a definitive implication should be made with caution.

Regarding the effects on GVA, the estimated coefficients are relatively higher than for EMP, indicating that changes in TOTALPUWASTETONS affect GVA more than EMP. A net positive effect is illustrated in all countries, although the definitive effect depends on the exact region and its neighbors.

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Additionally, the corresponding PU hard foam waste streams can therefore also be considered on a similar level, although the temporal variance poses a high uncertainty directly related to the availability of the PU hard foam for recycling. The quality of the PU hard foam after its end-of-life is also subject to uncertainty, as well as the exact waste streams that are not exclusively local and tied to an administratively defined region.

Model testing regarding sensitivity of the PU amounts has not proven to influence the estimated effects. Different methods of estimating the amounts of PU hard foam have also not resulted in significantly different results (using, e.g., data from collected end-of-life refrigerators). Different model specifications regarding the spatial econometric part have also not contributed to significantly diverging results. Future analyses can hopefully benefit of an extended timeframe of end-of-life PU hard foam data for refrigerators and insulation boards/sandwich panels, further fine-tuning (e.g., losses, processing constraints of PU hard foam), and a more refined regional disaggregation process.

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4 Appendices

4.1 Appendix A: Input-Output method

The analysis is based on a multiregional IO table, which provides interregional trade flows for Europe at the NUTS-2 level (Thissen et al., 2018). The database also captures the sectoral linkages of European regions with the rest of the world, with a specific focus on economically relevant countries such as the US and China.

The intersectoral and interregional linkages in the IO table can be represented in terms of matrix notation. Following Miller and Blair (2009), we consider a two-region economy, e.g. the Rheinisches Revier and the rest of Germany. Using r and s for the two regions, let there be three producing sectors (1, 2, 3) in region r and two (1, 2) in region s. In an IO framework, it is assumed that the output produced in sector 1 is either used as intermediate input (z) by other sectors or consumed as final demand (f) in the same region r or in region s. In our two-region example, the output of sector 1 in region r would therefore be expressed as

$$x_1^r = z_{11}^{rr} + z_{12}^{rr} + z_{13}^{rr} + z_{11}^{rs} + z_{12}^{rs} + f_1^r \quad (1)$$

where the first three components on the right hand-side of the equation express the *intraregional*, interindustry sales of sector 1, the following two components the *interregional*, interindustry sales of sector 1 and the last component, f_1^r, the intraregional sales of sector 1 to final demand. There will be similar equations for x_2^r and x_3^r, and also for x_1^s and x_2^s.

In addition, a set of so-called regional input coefficients for region r (and for region s) can be derived as:

$$a_{ij}^{rr} = \frac{z_{ij}^{rr}}{x_j^r} \quad (2)$$

The regional input coefficient indicates the amount of intermediate inputs from production sector i that is necessary to produce one unit of final product j within the same region r.

Interregional trade coefficients follow the same definition as regional input coefficients but refer to interregional flow of intermediate inputs. These coefficients can be expressed as

$$a_{ij}^{rs} = \frac{z_{ij}^{rs}}{x_j^s} \text{ and } a_{ij}^{sr} = \frac{z_{ij}^{sr}}{x_j^r} \quad (3)$$

Using the regional input and trade coefficients from equation (2) and (3), equation (1) can be re-expressed as

$$(1 - a_{11}^{rr})x_1^r - a_{11}^{rr}x_2^r + a_{13}^{rr}x_3^r + a_{11}^{rs}x_1^s + a_{12}^{rs}x_2^s = f_1^r \quad (4)$$

Considering not only the sectoral and regional interlinkages of sector 1 in region r, but also the interregional and intraregional trade flows of other sectors and of both regions r and s, equation (4) can be expressed in complete matrix notation as

$$(I - A)x = f \quad (5)$$

with $A = \begin{pmatrix} A^{rr} & A^{rs} \\ A^{sr} & A^{ss} \end{pmatrix}$ as the complete coefficient matrix for a two-region interregional model including, for example, $A^{rr} = \begin{pmatrix} a_{11}^{rr} & \cdots & a_{13}^{rr} \\ \vdots & \ddots & \vdots \\ a_{31}^{rr} & \cdots & a_{33}^{rr} \end{pmatrix}$.

Using standard matrices calculations, equation (5) can be transformed into

$$x = (I - A)^{-1} f \quad (6)$$

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where $(I - A)^{-1}$ is the so-called Leontief Inverse Matrix, which shows the sectoral and regional coefficients (so-called output multipliers) that measure the total effects on the economy because of an initial increase in production of a production sector. In other words, an increase in production of sector i in region r expressed by a change in the sales vector f initially requires higher demand for intermediate consumption, thus inducing additional production effects at the upstream supplier side expressed by a change in the output vector x.

Equation (6) can be extended to a multiregional IO framework, including more than two regions and three sectors, as it is the case in the context of our analysis. Based on the aforementioned IO table, the Leontief Inverse Matrix and output multipliers, respectively, can be derived to estimate the so-called spillover effects of each model region along its upstream value chains. Using further data from the IO table, it is possible to convert the IO output multipliers into GVA multiplier.

To conduct the IO analysis, we first need to define and allocate each model region according to the statistical NUTS-2 classification of European regions. This is the most detailed spatial level with available data on interregional and intersectoral linkages. In the case of the Rheinisches Revier, we choose the NUTS-2 regions Cologne and Dusseldorf as the statistical boundary for the model region. For the Metropolis GZM model region, the NUTS-2 region "Silesian Voivodeship" serves as the spatial unit. In addition, the Amsterdam Metropolitan Area is statistically defined according to the NUTS-2 region North Holland.

Using the IO table with data at the NUTS-2 level, we derive the economic structure of each model region, including its industrial and sectoral shares in total regional output and value added. The sales vector f in equation (6) is based on the sectoral production structure of each model region, which serves as the starting point for the economic spillover analysis, including the estimation of direct and indirect GVA effects. The indirect GVA effects of each model region measure its economic interlinkages with other regions in terms of intermediate inputs.

Finally, to obtain the regional share of total indirect GVA effects as illustrated in Figures 1-6, we calculate for each region on NUTS-2 level the ratio between the region's indirect GVA effect and the total indirect GVA effects of the model region, excluding the indirect GVA effects that are generated within the model region itself.

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4.2 Appendix B: GVC income approach in Input-Output analysis

Estimating the model region's downstream linkages in global value chains is based on the GVC income approach (Timmer et al., 2013, Los et al., 2015). In simple terms, the GVC income of the target region includes the value added generated in the production and export of final manufactured goods, as well as in the production of intermediate goods and services that are used in the production of final manufactured goods in other regions. Essentially, it encompasses all the value added in the production of *manufactured* final products.

This means that services that are directly consumed by individuals or service industries, such as personal and community services, retail activities, and business services, do not contribute to GVC income. To measure the regional importance of GVCs, the ratio between GVC income and regional GVA can be calculated using IO data and other calculations.

The methodology of the GVC approach is as follows: In line with Los et al. (2015), the value added generation in any of region-industries due to final demand for the output of industry m (e.g. waste industry) in region k (e.g., the model region Rheinisches Revier) are given by the elements of the vector

$$w^{mk} = v'(I - A)^{-1} F^{mk} i \quad (7)$$

In equation (7), i stands for a summation vector consisting of ones, which adds the elements in a final demand block F in row-wise fashion. F^{mk} consists of zeros, except for the elements in the row corresponding to industry m in region k. The square matrix $(I - A)^{-1}$ is known as the (global) Leontief inverse as aforementioned in equation (6). The vector v' consists of the regional and industry-specific GVA coefficients.

In the GVC income approach, we calculate the ratio between GVC income and total GVA of the model region to measure the regional importance of GVCs. For this, we set all rows in the final demand block equal to zero for industries m that do not belong to the manufacturing sector. That is, all final demand rows for manufacturing industries retain their values regardless of whether these industries are located in the model region or in other regions and countries as captured in the IO tables. In addition, we retain the value-added coefficients in vector v for the respective model region (e.g. Rheinisches Revier) and set all other elements of this vector to zero. This allows us to calculate the GVC income in the model region k expressed as the sums of the elements w^{mk}. Finally, we use the ratios between GVC income and total GVA of the model region as our measures of regional importance of GVCs. This calculation is conducted in a similar way for the national perspective.

4.3 Appendix C: Detailed regional PU hard foam estimations

This section delineates the sources of the data and the calculations to arrive at the estimated amounts of PU hard foam that are then used for estimating the spatial econometric models.

TABLE C1: VARIABLE DESCRIPTION AND CALCULATION OVERVIEW.

Variable name	Description	Calculation	Source
EMP	Employed persons (thousands) by NUTS 3 regions		Eurostat, NAMA_10R_3EMPERS
GVA	Gross value added at basic prices by NUTS 3 regions		Eurostat, NAMA_10R_3GVA

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TOTALPUWASTETONS	Sum of project relevant PU hard foam in tons per year by NUTS 3 region	= FRIDGEPUTONS + PANEL-PUTONS Upper/lower bound values are calculated by adding/subtracting 10%	Own calculations, (Conversio Market & Strategy GmbH, 2018)
TOTALPUWASTETON-SUP	Upper bound val-ues for TOTAL-PUWASTETONS	Upper bound values are calcu-lated by adding 10%	Own calculations
TOTALPUWASTE-TONSLO	Lower bound val-ues for TOTAL-PUWASTETONS	Lower bound values are calcu-lated by subtracting 10%	Own calculations
PANELPUTONS	Regional panel PU numbers per year by NUTS 3 region	= insulation+panel PU hard foam production in kilotons per year / LUKM2 * regional LUKM2 * 1000 Further assumptions (e.g., for Germany; Poland and Nether-lands equivalent): 68,88% of rigid PU production is buildings+construction PU, 2017: 198,3/288,1=68,88%, 68,88% of PU rigid foam per year. For years 2018-19 use CAGR 2015-2025 and before 2010 use CAGR from 2010-2017	Own calculations, (Conversio Market & Strategy GmbH, 2018)
FRIDGEPUTONS	Regional fridge PU amounts in tons per year by NUTS 3 region	= fridge PU hard foam produc-tion in kilotons per year / total population in persons * regional population in persons per year * 1000 Further assumptions (e.g., for Germany; Poland and Nether-lands equivalent): 0,041% of rigid PU foam prod is E+E incl. fridges: 11.9/288.1=0,041% aside from that similar as panels	Own calculations, (Conversio Market & Strategy GmbH, 2018)
DHHINC	Income of house-holds by NUTS 2 regions per year		(Eurostat, 2023a), NAMA_10R_2HHINC
POPDENSPERKM2	Population den-sity by NUTS 3 re-gion in KM2 per year		(Eurostat, 2023c), DEMO_R_D3DENS
POP	Population on 1 January by broad age group, sex and NUTS 3 re-gion		(Eurostat, 2023d), DEMO_R_PJA-NAGGR3

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LUKM2	Land use over-view by NUTS 2 regions (areas with buildings) in KM2 per year	= (Sum of LUE, LUD2, LUD3, LUD4, LUD5, LUD6, LUE1, LUE2, LUE3, LUE4) / total LU	Own calculations, (Eurostat, 2023b), LAN_USE_OVW

TABLE C2: ESTIMATED AMOUNT OF PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS IN THE MODEL REGIONS IN TONS IN 2019.

NUTS3	NAME	FRIDGE-PUTONS2019	PANEL-PUTONS2019	TOTAL-PUWASTE-TONS2019
DEA15	Mönchengladbach, Kreisfreie Stadt	40	68	108
DEA1D	Rhein-Kreis Neuss	69	231	300
DEA26	Düren	40	198	238
DEA27	Rhein-Erft-Kreis	72	148	219
DEA28	Euskirchen	29	262	291
DEA29	Heinsberg	39	132	170
DEA2D	Städteregion Aachen	85	148	233
NL329	Groot-Amsterdam	286	877	1163
PL228	Bytomski	57	121	178
PL229	Gliwicki	61	67	129
PL22A	Katowicki	96	29	125
PL22B	Sosnowiecki	89	138	227
PL22C	Tyski	52	72	125

SOURCE: BASED ON AUTHOR CALCULATIONS, (CONVERSIO MARKET & STRATEGY GMBH, 2018)

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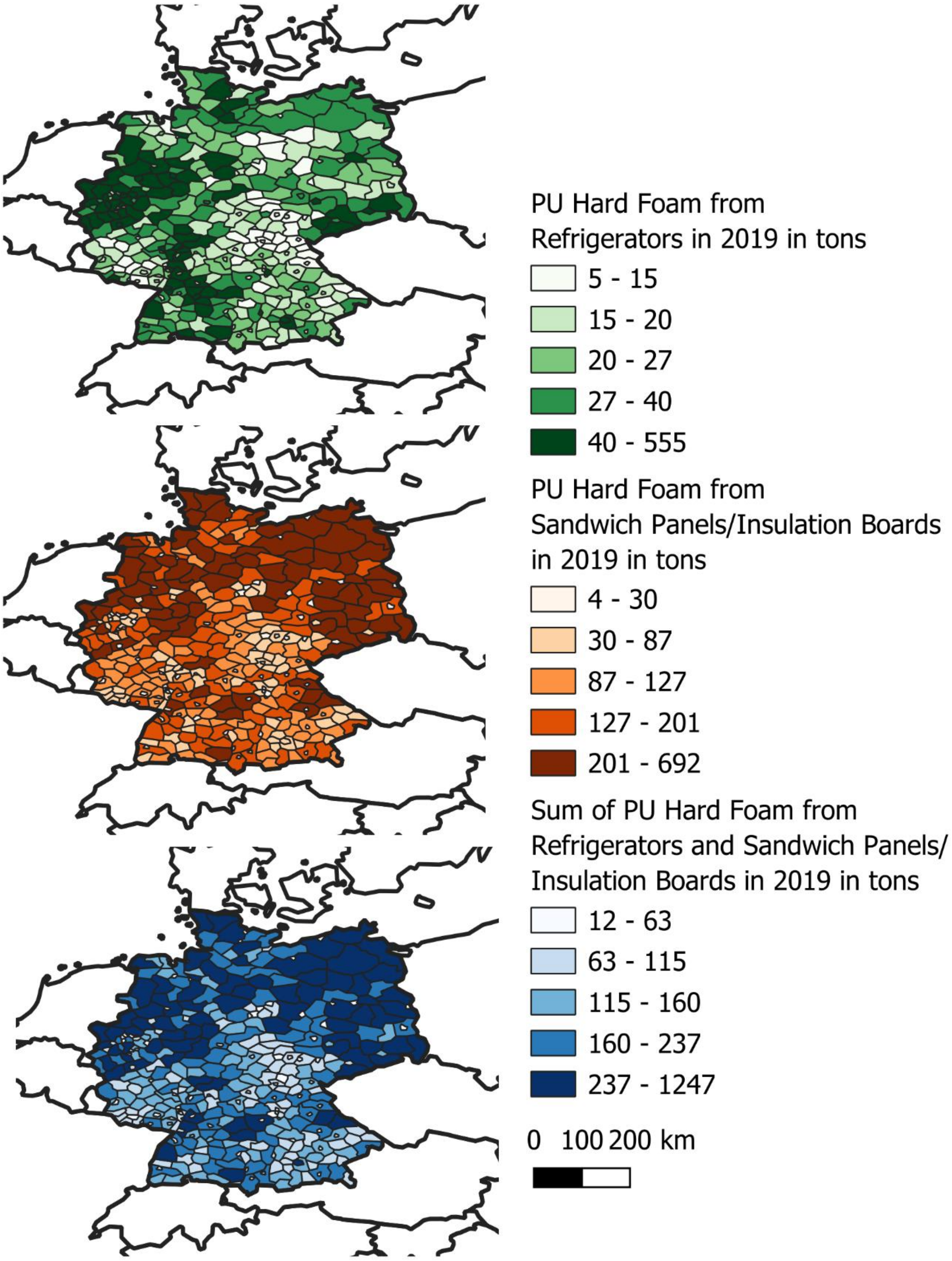
FIGURE C1: ESTIMATED AMOUNT OF PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS IN GERMANY IN 2019.



SOURCE: BASED ON AUTHOR CALCULATIONS, (CONVERSIO MARKET & STRATEGY GMBH, 2018)

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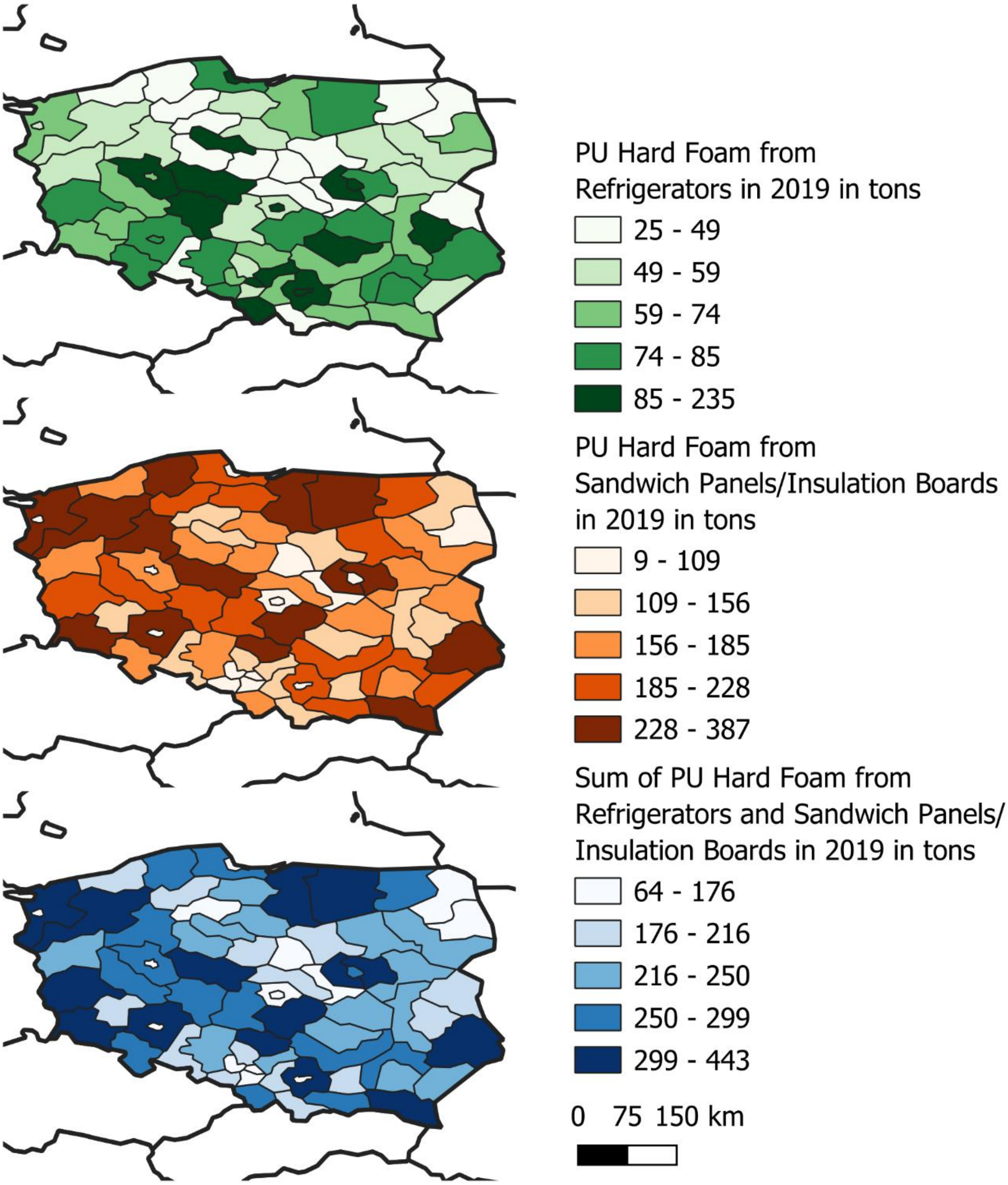
FIGURE C2: ESTIMATED AMOUNT OF PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS IN POLAND IN 2019.



SOURCE: BASED ON AUTHOR CALCULATIONS, (CONVERSIO MARKET & STRATEGY GMBH, 2018)

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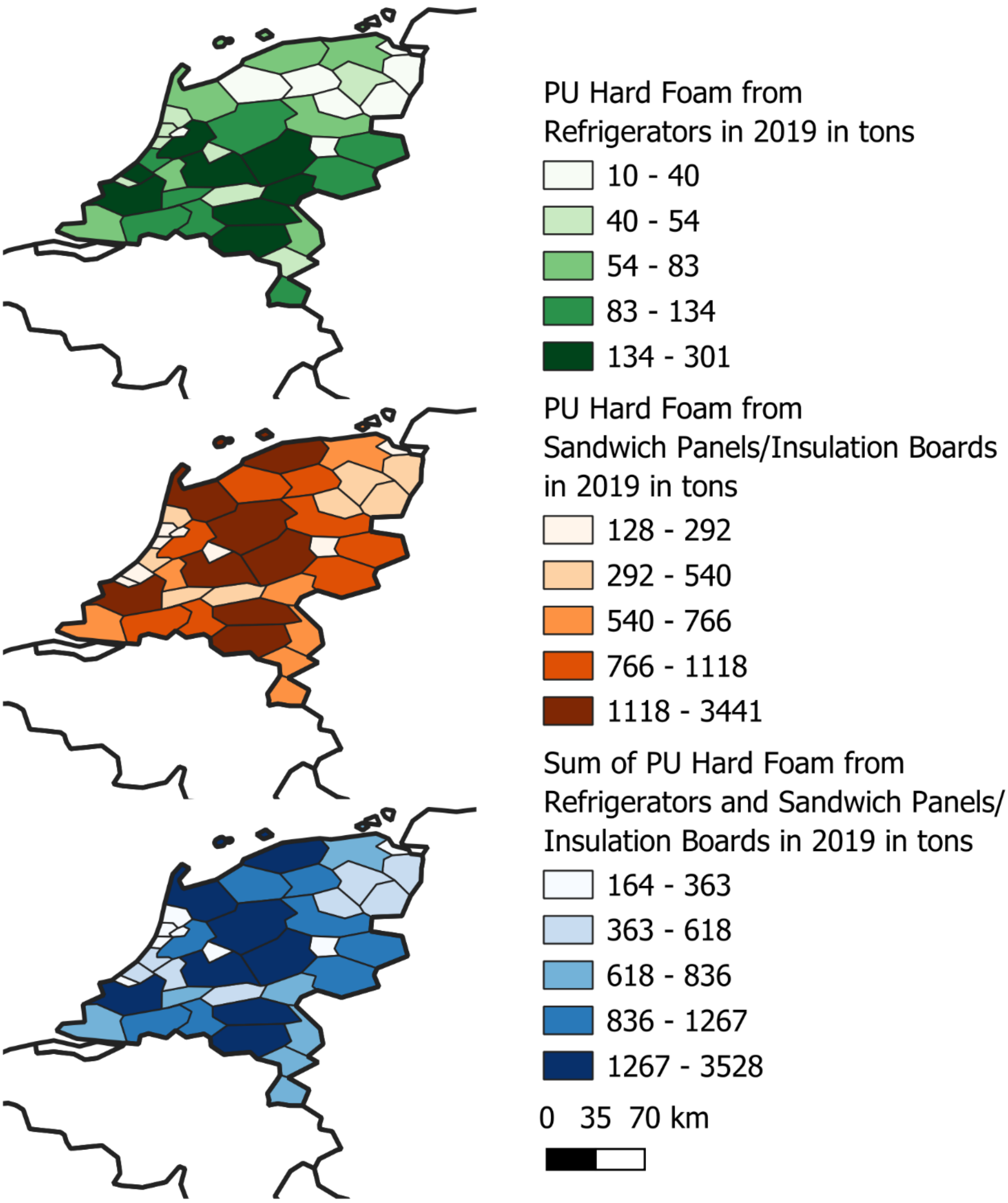
FIGURE C3: ESTIMATED AMOUNT OF PU HARD FOAM WASTE CONTAINED IN REFRIGERATORS AND INSULATION BOARDS/SANDWICH PANELS IN THE NETHERLANDS IN 2019.



SOURCE: BASED ON AUTHOR CALCULATIONS, (CONVERSIO MARKET & STRATEGY GMBH, 2018)

4.4 Appendix D: Spatial econometric approach

Spatial dependencies in regression models can be theoretically justified by viewing the spatial diffusion of observations as a converging process with friction (Keller, 2002). A rationale is using spatial

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dependency to capture unobserved variation in the dependent variable, particularly when slow-changing latent influences over distance are suspected (LeSage and Pace, 2009). This approach proves helpful in accounting for neighboring values related to cultural influences and infrastructure. However, it can also be applied to investigating factors influencing economic development in and between regions and their co-dependencies.

To identify spatial patterns, it is crucial to determine if the spatial distribution is non-random. Spatial autocorrelation occurs when there is a systematic pattern of pairwise correlation among regions, e.g., via the Moran I statistic (Getis, 2007, Cliff and Ord, 1970). The null hypothesis of Moran's I test asserts the absence of spatial autocorrelation and is tested for all variables used for the estimation models.

$$I = \frac{N}{S}\left(\frac{e'We}{e'e}\right) \tag{8}$$

Here $e = y - X\beta$ is the vector of the OLS residuals, and $\boldsymbol{W}$ is a spatial weight matrix. N is the number of observations, and S is a standardization factor equal to the sum of all rows of $\boldsymbol{W}$.

The spatial weight matrix W, defined as a contiguity-based matrix, ascribes neighbors on the condition of a shared border (i.e., a shared side of polygons). Each region is assigned a unique ID and related to each neighbor. The number of neighbors then allows the estimation process to quantify local spillovers among the regions.

Lagrange Multiplier (LM) testing for all model specifications indicates the Spatial Error Model as the robust model specification (Anselin, 1988). For this study, a Spatial Durbin Error Model, a variant of the SEM, is employed. This model estimates lagged variants of exogenous variables, providing additional flexibility (Elhorst, 2010).

The functional form of the model is defined as follows:

$$\begin{gathered} y = \alpha + \beta X + \theta W X + \delta + u \\ u = \lambda W u + \varepsilon \end{gathered} \tag{9}$$

In this setup, y represents an $n \times 1$ vector with the dependent variable showing variation across spatial observation units, while X is an $n \times k$ matrix containing observations of independent variables. The intercept is denoted by α, δ are individual region-fixed effects, and ε represents disturbances.

The SEM is characterized by the autoregressive error term with $\lambda W u$, representing a particular form of a non-spherical error variance-covariance matrix, where $E[\varepsilon i \varepsilon j] \neq 0$ for two locations $i \neq j$. Omitting the autoregressive error term renders unbiased estimators but inefficient, leading to biased statistical inference based on Ordinary Least Squares (OLS). The spatial parameter λ in the autoregressive error function is often seen as a nuisance parameter employed to improve β parameter estimates by modeling spatial dependence into the error term (Anselin, 1988, Le Gallo, 2014).

For this study, two SDEMs are executed for each of the three countries containing the model regions, one for GVA, one for EMP as the dependent variable. The model is estimated as a panel, data is used as described in Appendix C and logarithmized (natural logarithm) and tested for alternative specifications and as reduced forms, of the latter results are displayed in section 3.

The formulas for each region are as follows, with alternating regressors omitted as indicated by the full models' estimation. All models are estimated with the package *splm* in R (Millo and Piras, 2012, R Core Team, 2023).

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$$EMP_{i,t} = \alpha_0 + \beta_1 lnTOTALPUWASTETONS_{i,t} + \beta_2 lnPOPDENSPERKM2_{i,t} + \beta_3 DHHINC_{i,t} + \beta_4 TOTALPUWASTETONS_{i,t} * W + \beta_5 POPDENSPERKM2_{i,t} * W + \beta_6 DHHINC_{i,t} + \delta_i + u_{i,t}$$
$$u_{i,t} = \lambda W u_{i,t} + \varepsilon_{i,t} \quad (10)$$

$$GVA_{i,t} = \alpha_0 + \beta_1 lnTOTALPUWASTETONS_{i,t} + \beta_2 lnPOPDENSPERKM2_{i,t} + \beta_3 DHHINC_{i,t} + \beta_4 TOTALPUWASTETONS_{i,t} * W + \beta_5 POPDENSPERKM2_{i,t} * W + \beta_6 DHHINC_{i,t} + \delta_i + u_{i,t}$$
$$u_{i,t} = \lambda W u_{i,t} + \varepsilon_{i,t} \quad (11)$$

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