The physical structure of urban economies – comparative assessment

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Abstract

The metabolism of a city is dependent on anthropogenic and natural physical inputs of energy and materials, processes for transforming those inputs for urban activities, additions to the stocks contained within its spatial boundaries, and the waste and emissions handling.

The main purpose of this work consists on further developing methods that allow identifying the material consumption of activity sectors within a city. The method presented in this article allows the use of internationally available data (e.g. OECD Input Output matrices), which enables analysing a large range of urban areas. The method is applied to metropolitan economies in Europe (Lisbon and Paris) and Asia (Seoul-Incheon and Shanghai), and the variability of the physical structure of these economies is assessed. The urban areas are compared in terms of total and type of material input, destination of material inputs within the economy and analysis of the manufacturing sectors.

Resumo

O metabolismo de uma cidade depende dos fluxos físicos naturais e antropogénicos de materiais e energia, dos processos para transformar esses fluxos e usa-los em atividades urbanas, da acumulação de materiais ao stock existente e da administração dos resíduos e emissões.

O objetivo deste trabalho consiste no desenvolvimento de métodos que permitam identificar o consumo de materiais por setores de atividade. O método apresentado permite a utilização de dados disponíveis internacionalmente (ex. matrizes Input Output publicadas pela OCDE), possibilitando a análise de várias áreas urbanas. O método é aplicado às áreas metropolitanas de Lisboa e Paris, na Europa, e Seul e Xangai, na Ásia, sendo analisada a variabilidade da estrutura física destas economias. As áreas urbanas em causa são comparadas em termos do seu input total de materiais, dos diferentes tipos de materiais, do destino final dos materiais consumidos na economia e na análise dos materiais consumidos pelo setor industrial.

Introduction and objectives

As urban expansion and new patterns of economic activity have fed on each other, novel configurations for urban areas have emerged, such as mega urban regions, urban corridors and city-regions. Currently, urban areas account for over 48 per cent of the global GDP (BI, 2012), with many of these cities having become centres of international trade and commerce and hubs for regional and international connectivity.

Cities are engines of growth but also the key drivers for stronger and more relevant global environment-economy interactions (Seto & Satterthwaite, 2010). During their development stages, cities encourage or discourage the development of particular economic activities within their boundaries, and at each stage this defines their signature (typology), including the jobs, the economic output (Spence et al. 2009) or their dependence of material resources from elsewhere and, depending on how they process them, their impact on the environment (Kennedy et al, 2007).

The quantification of the requirements of materials and commodities needed to support human tasks in cities, including the removal and disposal of waste, is known as the urban metabolism (Wolman, 1965), as a parallel to the metabolisms of ecological systems. To fully describe the metabolism of a city, several factors need to be considered: anthropogenic and natural physical inputs of energy and materials, processes for transforming those inputs for urban activities, additions to the stocks contained within its spatial boundaries, and the fluid and reliable dispersion of wastes (Niza et al, 2009).

Progress towards urban sustainability will then depend, at least in part, on the reduction of resource input on the one hand and the further reduction of pollutant output on the other hand. Since material flows through the anthroposphere connect both of those ends, the Material Flow Analysis or Material Flow Accounting (MFA) approach offers considerable potential in helping to assess the path towards sustainability (Bringezu, 1999). The metrics provided by this type of approach allow understanding how natural resources uses correlate with urban economic activities and can enable the definition of priorities for action towards decreasing the pressure cities exert on the environment.

While some research has been made on the metabolism of urban areas, they are generally applied to a small set of urban areas as they require very detailed and specific data which is not commonly available (e.g. Barles, 2009; Schulz, 2007; Hammer and Giljum, 2006; Barrett et al. 2002). As such, it becomes very difficult to compare the results obtained for different cities, limiting the conclusions that can be drawn from these studies.

The main purpose of this work consists on further developing the methods developed at IN+/IST, Portugal, (Niza et al., 2009; Rosado et al., 2012) that allow decomposing material consumption through activity sectors stemming from the underlying idea of assuming a linear relation between the material flows and the number of workers of economic activities existing in an urban area. The method presented in this article adapts and simplifies those methods to allow the use of internationally available data (e.g. OECD Input Output matrices) for a large range of countries. The method is applied to metropolitan economies in Europe (Lisbon and Paris) and Asia (Seoul-Incheon and Shanghai), allowing assessing the variability of the physical structure of these economies. Urban areas are compared in terms of total and type of material input, destination of material inputs within the economy and analysis of the manufacturing sectors.

Methodology

The comparison between the four metropolitan areas is performed using metrics as demographics, economic structure and physical structure. The physical structure of an urban economy is described by the material throughput of that economy. To measure these flows, it is necessary to consider: Inputs – domestic extraction of resources, imports of raw materials and products; Internal processes – intermediate and final consumption; Addition to stock – accumulation of materials in the system; Outputs – emissions and wastes, exports of raw materials and products.

The material inputs of an urban area may derive from locally extracted materials, imports from the rest of the country or imports from abroad. The raw materials and intermediate goods imported are going to be used by economic activities to produce final goods that will eventually be used for final consumption, either by the economic activities themselves or by the citizens and the government, or exported. Allocating materials to economic activities allows describing the production structure of the urban area in mass units.

Part of the consumption is accumulated to the material stock of the local economy (namely as buildings, infrastructures, durable goods). The remaining leaves the economy as valuable products, waste and emissions (be it to the local environment or outside it). Additionally, there is a large fraction of materials that are imported and to a great extent re-exported, designated transit or crossing flows. This fraction hardly becomes part of the urban economy since the region (through its harbours, train-stations and airports) works essentially as gateway to other regions.

Commonly, the structure of statistical records does not include data at urban level; consequently the accounting includes estimating values from existing data, usually at higher scales (namely regional or even country level). Niza et al. (2009) and Rosado et al. (2013) developed a method to account and disaggregate urban flows using data produced for several scales. The method is based on EUROSTAT's economy-wide material flow accounting (EUROSTAT, 2001), but requires detailed statistics, particularly at the urban area level, such as International Trade Statistics: to the urban area; Transport Statistics: within the urban area and between the area and the other regions of the country; Industrial Production Statistics; Mineral extraction; Agricultural harvest; Forestry; Fisheries; Industrial waste; Municipal solid waste and Emissions. While some statistics are available for many urban areas around the world, transport statistics are rare, making it difficult to know which materials and products are imported to an urban area from the rest of the country.

The method developed in this article consists on estimating the metabolism of an urban area by scaling down the metabolism calculated for the country. The calculation of the country urban metabolism is performed using published Input-Output tables (IO tables) (OECD[1]). These tables characterize the sales from each economic sector to the other, the consumption of households, the consumption of the government, the acquisition of buildings and machinery by companies (gross fixed capital formation, GFCF) and the

[1] http://www.oecd.org/trade/input-outputtables.htm, accessed March 2013.

exports – these are the demand parameters of IO tables. The input of materials to the country is obtained through domestic extraction and trade statistics (FAO[2], UN Comtrade[3] among others).

In order to distribute the input of materials by the economic sectors, the final consumption and the exports, each material and product entering the economy is first allocated to the economic sectors that produce them. This is performed using correspondence tables linking commodities (expressed in SITC[4], EW-MFA[5], HS[6] or CN[7] nomenclatures) to economic activities (expressed in nomenclatures such as ISIC[8] and NACE[9]), and conversion tables for nomenclatures of materials and for nomenclatures of economic activities.

The distribution of materials through the economy is then made based on the sales registered by each economic sector, with the materials coming from each sector being split by all the economic sectors, final consumption and exports according to the purchases made from that sector. These calculations enable the estimation of how materials are distributed within a country economy. Due to the large variety of materials and products that enter an economy, making it difficult to even analyse the results, the products are converted to a nomenclature representing categories of materials named MATCAT (Rosado et al., 2013). This nomenclature was created at IST, and establishes a correspondence between products listed in the CN and the materials that constitute them (Table 1). The MATCAT nomenclature considers 6 categories of materials (fossil fuels, metallic minerals, non-metallic minerals, biomass, chemical and others), with a total of 28 subcategories. This enables an easier analysis of the results, and allows identifying which types of materials is an economy more dependent on.

Table 1 – Nomenclature for Material Categories, MATCAT (Rosado et al., 2013)

Fossil Fuels (**FF**)	FF1	Low ash Fuels
	FF2	High ash Fuels
	FF3	Lubricants and Oils and Solvents
	FF4	Plastics and Rubbers
Metals (**MM**)	MM1	Iron, Steel Alloying Metals and Ferrous Metals
	MM2	Light Metals
	MM3	Non-Ferrous Heavy Metals
	MM4	Special Metals
	MM5	Nuclear Fuels
	MM6	Precious Metals
Non-metallic minerals (**NM**)	NM1	Sand
	NM2	Cement
	NM3	Clay
	NM4	Stone
	NM5	Other (Fibers, Salt, inorganic parts of animals)
Biomass (forestry, crops and animal products) (**BM**)	BM1	Agricultural Biomass
	BM2	Animal Biomass
	BM3	Textile Biomass
	BM4	Oils and Fats
	BM5	Sugars

[2] http://faostat.fao.org/, accessed March 2013.
[3] http://comtrade.un.org/db/dqBasicQuery.aspx, accessed March 2013.
[4] Standard International Trade Classification
[5] Economy-Wide Material Flow Accounts
[6] Harmonized System Codes
[7] Combined Nomenclature
[8] International Standard Industrial Classification
[9] Statistical Classification of Economic Activities in the European Community

	BM6	Wood
	BM7	Paper and Board
	BM8	Non-Specified Biomass
Chemicals and Fertilizers (**CF**)	CF1	Alcohols
	CF2	Chemicals and Pharmaceuticals
	CF3	Fertilizers and Pesticides
Others (**O**)	O1	Non-Specified
	O2	Liquids

The key methodological step to scale down consists on using the share of the country's workers that exist in the urban area, per economic activity, as well as the share of population. The share of workers is used to estimate the amount of materials consumed by each economic sector, as well as the amount of materials and products produced by each economy sector that are for international export. The final consumption by households and by the government was estimated using the share of population.

This method determines that the material input to an urban economy is composed of the materials locally consumed by the economic sectors (households, government and companies) and the materials used for international exports: Material input = local consumption + international exports, where local consumption= consumption by households + consumption by government + consumption by companies.

Though the materials used for exports to the rest of the country are included in the direct material input they are not identified through this method. Therefore, when comparing to the EUROSTAT material flows indicators (EUROSTAT, 2001) the material input is a value between the Direct Material Input (Domestic Extraction + Imports) and the Domestic Material Consumption (DMI – Exports), with the local consumption being equal to the DMC. Consequently, comparison of the results of this study with other urban metabolism studies should be performed carefully.

Moreover, the methodology described in this work does not identify the crossing flows within an urban area. However, as the total material input to an urban area is determined by the total final consumption and the exports, the materials that cross the urban area are also not accounted in the inputs, thus enabling a material balance.

Results and discussion

The methodology was applied to four urban areas (Seoul-Incheon, Shanghai, Paris and Lisbon) for the year 2000. Results comparing the total material input, the local consumption, the weight of the different economic sectors in terms of material consumption and analysis of the manufacturing sectors, are shown in the next peragraphs.

The socioeconomic characteristics of the chosen metropolitan areas are very diverse, in terms of sheer size, population and relative wealth, as can be seen on Table 2. From the four urban areas under analysis, Seoul-Incheon was the largest metropolitan region with an area above thirteen thousand square kilometres, more than four times the shortest, Lisbon. Seoul-Incheon was also the most populous of the metro areas, followed by Shanghai, with eight and six times more population, respectively, than the least populated, Lisbon.

Shanghai was also the densest metro area with more than two thousand habitants per square kilometre, which is more than two times denser than Lisbon. It is interesting to notice that while Seoul-Incheon is the most populous urban area, Shanghai is a much more compact city, with the population density of Seoul-Incheon being three quarters as that of Shanghai.

Table 2 – Demographic and output indicators of the four metropolitan areas

	Area (km^2)	Population (thousand)	Share of national population	Pop. Density (hab/km^2)	Nominal GDP (mils $)	Share of national GDP	GDP per capita (thousands $)
Lisbon[10]	3002 (2003)	2.662 (2001)	26% (2001)	887	41.345 (2000)	38% (2000)	15,53
Paris[11]	12012 (2006)	10.952 (1999)	18% (2006)	912	371.300 (2000)	28% (2000)	33,90
Seoul-Incheon[12]	13595 (2000)	21.354 (2000)	46% (2000)	1.571	208.975 (2000)	44% (2000)	9,79
Shanghai[13]	7705 (2000)	16.086 (2000)	1% (2000)	2.088	57.731 (2000)	2% (2000)	3,59

The wealthiest area per capita was Paris, followed by Lisbon. The metro economies that contributed more to the country wealth were Seoul, with almost half of the country output, and Lisbon, with more than a third. Shanghai, on the other hand, represented only 2% of the country GDP, which can be explained by the large country that is China, with Shanghai having only 1% of the population of the country at the time.

The application of the methodology showed that there is not a correlation between the wealthiest areas per capita and the ones that consume more materials per capita, as can be seen in Table 3. While Paris was the richest urban area and had the highest consumption per capita (both in terms of material input and local consumption), the Seoul-Incheon urban area had the second highest material input and material consumption but a much lower GDP per capita when compared to Lisbon. Furthermore, Shanghai had a very low GDP per capita when compared to the other urban areas under analysis, but its material input and local consumption was of the same order as all other urban areas.

Table 3 – Total and per capita material input and material consumption of the Lisbon, Paris, Seoul-Incheon and Shanghai metropolitan areas, 2000. Own calculations.

	Material input		Local consumption	
	Total [kt]	Per capita [t/cap]	Total [kt]	Per capita [t/cap]
Lisbon	34.880	13,1	31.510	11,8
Paris	260.698	23,8	224.644	20,5
Seoul-Incheon	369.521	17,3	322.400	15,1
Shanghai	175.806	10,9	166.796	10,4

[10] http://www.ine.pt/
[11] http://www.insee.fr/
[12] http://kosis.kr/eng/
[13] http://www.stats-sh.gov.cn/

When assessing the material input structure of the four urban areas, as shown in Figure 1, it is possible to see that non-metallic minerals and biomass are the most important material categories. This can be explained by the large and complex infrastructures that are required for urban areas to function, as well as the use of biomass products to feed the population or food industries. These two types of materials account for between 58%, in the case of Seoul-Incheon, and 83%, in the case of Lisbon, of the total material input.

In the case of the non-metallic minerals share, the MatCat subcategory NM4 (stone), represents more than 95% of the material input in Seoul-Incheon and Shanghai, while in Paris and Lisbon it corresponds to below 80% with NM1 (sands), being responsible for between 12% and 18%.

In terms of biomass, the subcategories BM1 (agricultural biomass), BM6 (wood), and BM8 (non-specified biomass), are the most relevant. Together, they account for over 85% of all biomass used in each urban area.

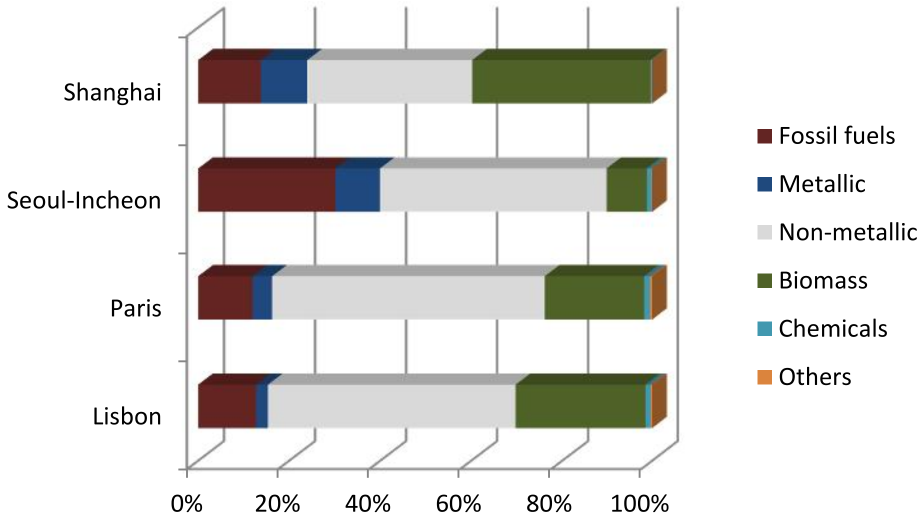

Figure 1 – Material input structure of the four urban areas, 2000. Own calculations.

The urban areas of Lisbon and Paris rely on very high shares of non-metallic minerals use, above 50%, and have significant biomass needs, around 25%. The urban area of Seoul-Incheon relies also significantly on non-metallic minerals, close to 50%, but also uses a high amount of fossil fuels, reaching up to 30% of the total material input. Finally, the urban area of Shanghai is characterized by using a very significant amount of biomass, close to 40%, relying also on non-metallic minerals (around 35%).

The high share of non-metallic minerals in Lisbon and Paris can be explained by the boom of construction that these cities were experiencing during the beginning of the 2000's. In the particular case of Lisbon, the city was undergoing significant transformations in some areas, such as the Parque das Nações area, with several new buildings being constructed.

The high share of fossil fuels consumption in Seoul-Incheon can suggest that the industry in the area is highly energy intensive, there is specific industry for fossil fuel products or there is a heavy use of private transport (or a mix of these hypotheses).

To assess the diversity of material usage in the urban areas under analysis, Figure 2 shows the cumulative share of total material input, with the 28 materials subcategories defined in MATCAT. For each urban area, the subcategories are ordered by their share of total material input, from the highest to the lowest. The results show that only a small number of subcategories have a significant share of total material input in all urban areas.

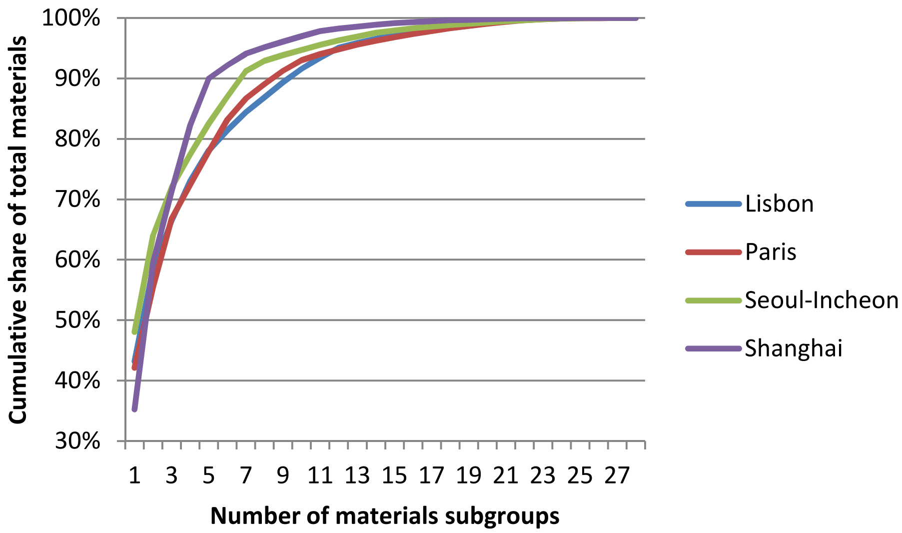

Figure 2 – Cumulative share of the 28 material categories in the four metro areas, 2000. Own calculations.

The urban areas of Lisbon and Paris are the more diverse in terms of material input subcategories, while Shanghai is the more dependent on specific materials subcategories. Interestingly, this contrasts with the results obtained from the material input structure, shown in Figure 1, in which Shanghai was the urban area that present the more balanced structure. This is due to the fact that there is one subcategory in each major material category that is responsible for more than 60% of the input of those categories in Shanghai.

This diversity of materials used in the urban areas of Lisbon and Paris can be observed by the fact that to achieve a share of 90% of the material input, they required 10 and 9 different subcategories of materials, respectively. Seoul-Incheon and Shanghai, on the other hand, required only 7 and 5 subcategories, respectively. The division of these subcategories in the main categories is as follows:

- Lisbon: 10 subcategories, being 4 related to fossil fuels, 3 to biomass and 3 to non-metallic;
- Paris: 9 subcategories, being 3 related to fossil fuels, 2 to biomass, 3 to non-metallic and 1 to metallic minerals;
- Seoul-Incheon: 7 subcategories, being 4 related to fossil fuels, 1 to biomass, 1 to non-metallic and 1 to metallic;
- Shanghai: the 5 subcategories are divided into 1 of fossil fuels, 2 of biomass, 1 of non-metallic and 1 of metallic.

It is important to notice that while the diversity of material input may indicate a diversified economy, results need to be considered carefully, as they may also indicate that some urban areas do not have material intensive industries, leading to no type of material being dominant. To better understand this issue, the material input per sector of the economy is shown in Figure 3.

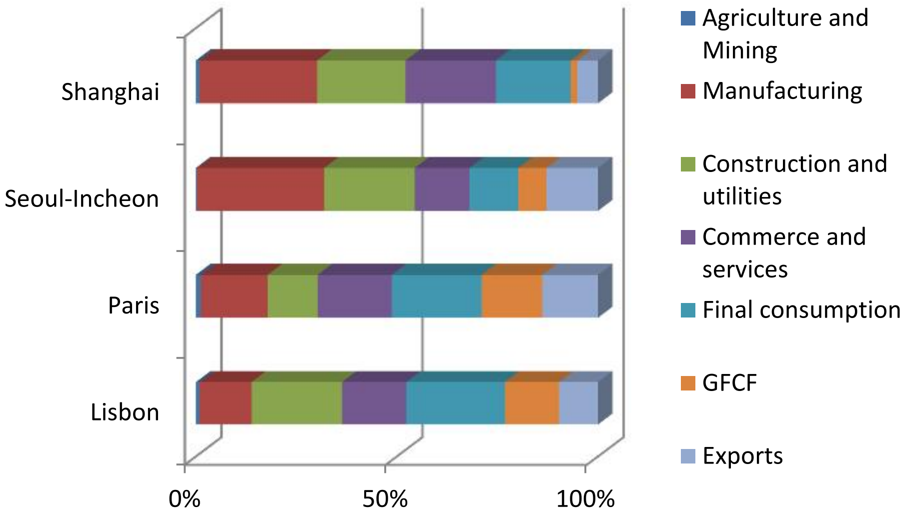

Figure 3 – Material input per sector category in the four metro economies, 2000. Own calculation.

As can be seen from the figure, Paris and Lisbon present again very similar shares of the material input with the manufacturing sector representing only between 13% and 17%, the final consumption between 22% and 25% and the gross fixed capital formation (GFCF) between 13% and 15%. This high share of material input to GFCF will have significant impacts in the evolution of the urban area, as it mainly includes material with long life spans that are not consumed in that year, but rather stay within the city for several years (material stock).

Seoul-Incheon and Shanghai have a material input to the secondary sector (manufacturing + construction and utilities) of around 50% of the materials that enter these economies. The manufacturing sector, in particular, uses a very high share of the materials of these economies, around 30%. These are also the economies that have the least share of materials consumed by the gross fixed capital formation.

In what concerns exports, Shanghai is the metro area whose share of materials is the lowest, with only 5% of the materials input being exported from the urban area. On the other hand, Lisbon, Paris and Seoul-Incheon have very similar shares of materials being exported, with 10%, 14% and 13% respectively.

The low share of material use in agriculture and mining is not surprising, as the areas under analysis are densely populated, much more than the rest of country, with little space available for exploring raw materials such as biomass or minerals.

The results obtained support the last decades developments of these economies where the Asian metro areas specialized in producing tradable products (Shanghai and Seoul) while the Western Europe metro areas specialized in services and non-tradable products (see for instance the share of Final Consumption and GFCF in Paris and Lisbon).

In this analysis, the material input to the manufacturing sector represents the self-consumption of products by companies. Using the consumption of materials by the different types of industries as a proxy of the importance of each industrial sector, Figure 4 shows the industrial structure of each urban area.

As can be seen from the figure, Lisbon had the least diversified manufacturing sectors, with the biomass products and the construction products industries accounting for 40% and 30% of the total material input. On the other hand, Seoul-Incheon appears to be the more diverse economy, with all types of industries accounting for at least 10% of the material input to the manufacturing sector.

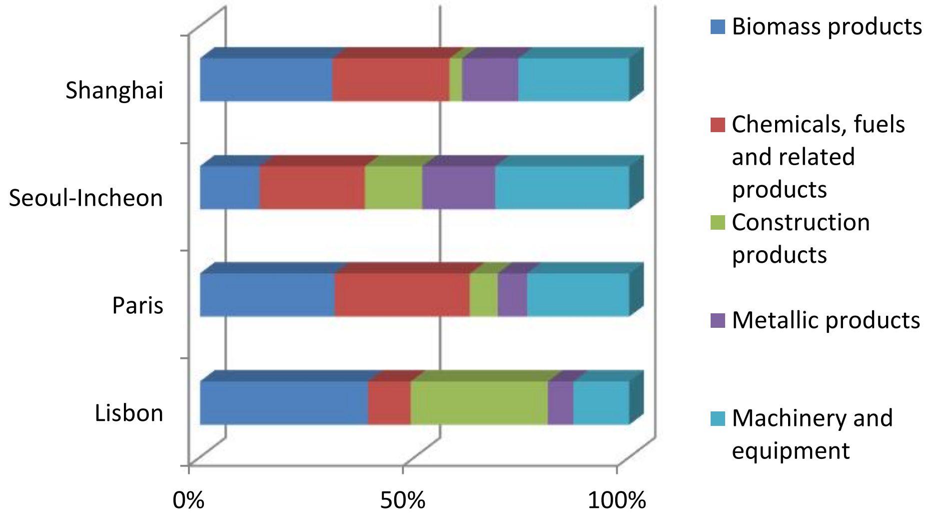

Figure 4 – Share of material input for the manufacturing sector, used by each industry type, for the four metropolitan areas, 2000. Own calculations.

Generally, the biomass products industry is very significant in the urban areas under analysis, being responsible for more than 30% of the products consumed by manufactures in all the metro areas, with the exception of Seoul-Incheon, in which this share was only 14%. The next most consuming industries are the chemicals and fuels (e.g. 32% in Paris, 27% in Shanghai and 25% in Seoul) and machinery and equipment (e.g. 31% in Seoul, 26% in Shanghai and 24% in Paris), which can have high economic value.

When comparing the diversity of the industries with the socioeconomic characteristics of the urban areas, there does not seem to exist a direct relation between the structure of the manufacturing sector and the GDP per capita. This can also be due to the large impact that commerce and services have on the GDP of urban areas, while they are low material intensive. However, the low number of urban areas under analysis does not allow drawing strong conclusions on the correlation between these factors. Nonetheless, it is interesting to notice that urban areas with more diversified manufacturing sectors are also the ones that have more population, thus not being required to specialize in only one or two economic activities.

Conclusions

The study of urban areas in terms of how to drive their economic growth and the impact they have on the environment has become one of the more important topics in the world due to the growing urbanization trends worldwide. However, more than focusing on CO2 emissions that occur in urban areas, cities are being viewed from a holistic approach, with research trying to understand the metabolism behind a city, i.e. which materials enter the urban area, how they are used within the city and how they leave it.

This research work presents a method for estimating the metabolism of urban areas, based on the analysis of national metabolisms and the assumption that the flow of materials is proportional to the share of workers within each economic sector. The methodology was applied to four urban areas (Lisbon, Paris, Seoul-Incheon and Shanghai), using the year 2000 as reference.

The results showed that the metabolisms of Lisbon and Paris are very similar, being more dependent on non-metallic minerals, while Seoul-Incheon and Shanghai have different metabolisms, consuming significant shares of fossil fuels and biomass, respectively. In terms of the destination of the materials that enter the urban areas, Shanghai and Seoul direct most of it to their economic sectors, particularly the manufacturing sector, while Paris and Lisbon direct them more towards final consumption, GFCF and exports.

In terms of the development of the manufacturing sectors, the results point to the indication that metropolitan areas with higher population are able to diversify their manufacturing sectors, and thus extend their economic activities. However, the conclusions that can be drawn from this study need to be taken lightly as only four urban areas where analysed.

The potential for this methodology will continue to be studied through its application to more urban areas, which can enable the clustering based on their metabolism. Furthermore, the comparison of urban areas and other regions of a country can provide insights on how prepared is a region to support and trade with its neighbours, which might have a significant impact on its economic development. Finally, the methodology will also be used to analyse urban areas over several years, which can help define evolution patterns for urban areas, and therefore help guide the development of the new urban areas appearing throughout the world.

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