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INTERFACER PROJECT RESULT

THE FAB CITY INDEX

a toolkit for measuring progress towards a circular economy

INTERFACER

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01 Introduction

Fab Cities have set themselves an ambitious goal: by 2054, they want to have completed their transformation to a full circular economy according to the DIDO-Paradigm (Diez, 2018). That means, that they have to produce everything that is consumed within their boundaries by themselves, they neither import raw materials nor export any waste, nor do they emit greenhouse gasses above a sustainable threshold. Only data is imported or exported. Thus, material input to production has to come from within the city by means of urban mining, recycling, upcycling or re-use. So, the circular economy is even more ambitious than just a (re-)localized economy that could still import raw materials and would only focus on manufacturing in the city's territory. Obviously, no city in Europe, and certainly no big city with a population over half a million inhabitants, is anywhere near such a fully circular economy today. On the contrary, five decades of de-industrialization have left many European cities with a dwindling manufacturing capacity (Rowthorn & Ramaswamy, 1997; Kollmeyer, 2009, Škuflić & Družić, 2016). A great deal of goods must be imported. Manufacturing has moved offshore, and so has production in general if we include food and energy resources. And yet the production base has to be rebuilt if Fab Cities are to accomplish their 2054 goal.

However, what production capacity has exactly to be rebuilt is not self-evident. So, in addition to spurring innovation in digitization, production machinery and recycling capacity, a Fab City needs to evaluate where it stands on its way to a fully circular economy. Which production sectors are strong and economically sound, which are underdeveloped or even missing? To assess the state of a Fab City on its way towards the 2054 goal, a measure, or a toolkit of measures, would be needed.

The first to address the need for such measures have been Fab City Grand Paris and Utopies. In 2018 they introduced the concept of the Fab City Index (Florentin et al., 2018). It comprises three sets of measures: the priority of an economic sector in a Fab City's strategic agenda, its self-sufficiency with regards to the 2054 goal and the index number itself which can attain a value between 0 and 100. 0 means: nothing is produced within the city boundaries, 100 means: the urban economy is fully circular, nothing has to be imported (and no waste to be exported). This index number aims to make progress in different Fab Cities comparable and give incentives to step up efforts in building a circular economy.

Unfortunately, the Fab City Index as conceived by Fab City Grand Paris and Utopies is closed source. There is no documentation yet, how the index value is calculated nor which data are used. That means that other Fab Cities cannot replicate the analysis on their own. Given the centrality of the open-source paradigm for the Fab City concept, the sub-project WP 3.3 of the INTERFACER project thus aims to develop a framework for an "open-source Fab City Index" that could be applied by other Fab Cities at least in Europe independently. In what follows we propose such a framework by taking the city of Hamburg as an example.

01.1 Theoretical motivation

Indexes have long been in use to capture the change of state of an economy or a society over time and make it comparable to other entities. One well-known example is the consumer price index. It collects price data for numerous goods from a representative market basket in a given year in a standardized way and records their price increase against the previous year. Goods are grouped in categories the price increase of which are given individual weights that reflect their demand and everyday consumption, thus their current relevance. The weighted price increases of the categories are summed up and yield the index number, i.e., the aggregated price increase over all categories against the previous year (or the base year)[1]. The increase marks the inflation rate. If for instance the index value for the current year is 1,09, the market basket is 9 % more expensive than in the previous year. The weighting is important because different categories of goods experience different price increases that are not significant individually but only in aggregation.

Another example for an index number is the Gini Coefficient, which is an index for the degree of inequality in the distribution of income or wealth in a country. Mathematically it is not a sum, but the ratio of two geometrical areas that represent distributions of wealth in the population. The index number can attain values between 0 and 1 – 0 marks perfect equality, 1 stands for maximum inequality, that is one individual owns the whole wealth of a country. The Gini Coefficient is used to compare the degree of equality between different countries and can thus, given equality is a value in a society, inform policy makers to take measures against rising inequality if the index value rises over a longer period.

In a similar way, a Fab City index could be developed that aggregates the development of local production and recycling capacities of a city's economic sectors into a single number. With it, a Fab City's progress over time can be quantified and made comparable to other cities. At the same time it can provide a more detailed look into a city's development towards a Fab City because, analogous to the consumer price index, it requires a thorough analysis of individual economic sectors. Here, a typical measure for local production capacity in a certain sector could be the share of a product in local demand that could theoretically be manufactured within a Fab City. If for instance a Fab City can produce half the number of new cars that are actually bought over the year, the share and thus the measure of the respective sector is 50 %. To make results comparable across different Fab Cities the measures should follow standardized classifications of economic sectors or categories of goods: for the production side, statistics are ordered according to the NACE classification scheme that was introduced for national economic statistics within the EU in 2006 (European Commission 2008)[2]; for the consumption side statistics follow the COICOP classification (United Nations 2018)[3].

[1] Technically it's compared to a base year, that is reset every five years.
[2] Regulation (EC) No. 1893/2006. NACE stands for the French term "nomenclature statistique des activités économiques dans la Communauté européenne". It was in Germany as WZ 2008 (WZ for "Wirtschaftszweige).
[3] COICOP stands for "Classification of Individual Consumption According to Purpose".

With these measures, institutions and agencies that advance the Fab City concept would be able to make informed decisions for which economic sectors and categories of products they would have to step up efforts in order to approach self-sufficiency.

02 The French concept

To calculate an ideal Fab City Index and assess the state of different economic sectors would require complete and exact data on production and consumption within the urban territory. For instance, how many sneakers, washing machines or other goods have been bought and how many of them have been manufactured within Fab City? These data do not exist yet. There is no count of individual items manufactured and bought over a year. Thus, the Fab City Index concept as conceived by Fab City Grand Paris and Utopies works with an indirect modeling approach which draws on several databases about, among others, economic data of companies, household income, imports and exports. The LOCAL SHIFT model developed by Utopies analyzes 257 sectors which are aggregated to 12 macro-sectors:

• Agriculture, fishing industry • Extractive industries • Forestry, woodwork • Mineral construction materials	• Metal industry • Machines / Equipment • Other manufactured goods • Food and beverage	• Fashion,Textile • Paper, cardboard, printing Chemistry • Plastic, rubber

Each macro-sector is assigned a value between 0 and 10 for two dimensions: level of self-sufficiency and level of priority. Self-sufficiency means "the territorial entity's capacity to cover local demand for a given sector", while priority indicates a "sector's strategic importance with regard to local demand". The results for all sectors are finally aggregated into a final score between 0 and 100 which is the index number. A score of 100 means that a Fab City has reached the state of a fully circular economy and can produce its complete demand by itself. For Paris a Fab City Index of 37,58 in 2018 and a level of self-sufficiency of 8,7 % has been calculated (Florentin et al., 2018).

While this approach is truly pioneering work, it has three shortcomings. Firstly, the LOCAL SHIFT model is closed source. How and under which assumptions the data is processed is not revealed, thus other Fab Cities cannot replicate the analysis on their own. Secondly, the 12 aggregated macro-sectors represent too closely the divisions of the NACE classification. On the urban level, extractive industries – like oil production – and mineral construction materials are either not that relevant or simply not existent. On the other hand, NACE division C26, Manufacture of computer, electronic and optical products, is probably subsumed under Machines/Equipment which does not match its importance for an urban economy in the early 21st century. Repair and recycling is even absent in the 12 macro-sectors whereas both would be of utmost importance for a circular economy. Thirdly, it is not clear how consumption enters into the model.

03 The Hamburg approach

According to the Fab City Global Alliance’s emphasis on an open-source approach towards production, documentation and operations, it would be important that these measures be based on openly accessible data. Thus, we suggest an alternative approach that draws on data publicly available for Hamburg. Though these data are far from being complete, they enable us to make a first assessment of where Hamburg stands with regards to becoming a Fab City.

However, the NACE classification has inherited a fordist perspective on the economy which is heavily extractive in its production of resources and gives much weight to classical industrial sectors like the construction of machinery including vehicles of all sorts. However, the rationale of a Fab City's circular economy should not be to just replicate the current system of manufacturing and consumption with local means. It has to take into account that the current system is inherently not sustainable because it relies too much on extraction and growth of output. At the same time, the shift of major cities in Europe towards an economy centered around services which today use digital technologies in one way or the other has to be considered. Thus, we suggest 16 macro-sectors that partly differ from the aggregation in the French approach. These sectors are shown in Tab. 1. For each sector corresponding metrics and/or relevant NACE divisions or groups are given.

Tab. 1. The 16 macro-sectors which have to be monitored for measuring the progress towards a fully circular economy.

	Macro-sector	Metric	NACE
1	Energy	MWh/TJ renewable	(D35)
2	Water	Groundwater supply im Mio. m^3	(E36)
3	Agriculture and Fishing	Global hectares	A01, A03
4	Food and Beverages	Production value vs. consumption expense in €	C10, C11
5	Forestry and Products of Wood	[Estimate]	A02, C16, C18
6	Textiles and Clothing	Production value vs. consumption expense in €	C13, C14, C15
7	Chemical Products	Production value vs. consumption expense in €	C19, C20, C21, C22
8	Extractive Industries, Mining and Quarrying	Biomass production (no fossil or mineral deposits)	B5, B6, B7, B8
9	Metal Industry	Production value vs. consumption expense in €	C24, C25
10	Machinery and Equipment	Production value vs. consumption expense in €	C27, C28
11	Vehicles and Transport Equipment	Production value vs. consumption expense in €	C29, C30
12	IT and Communication	Production value vs. consumption expense in €	C26, C18.2
13	Other manufactured goods	Production value vs. consumption expense in €	C23, C32
14	Construction	Number of companies	C41, C42, C43
15	Repair	Production value vs. consumption expense in €	C33, G45, S95
16	Waste and Recycling	Amounts in t	(E37, E38, E39)

03.1 Data

For energy, data is available from the Statistical Office for Hamburg and Schleswig-Holstein[4], for water from the local provider Hamburg Wasser[5]. For productive sectors, we draw on data for agriculture and for manufacturing sectors as they are being collected by the Statistical Office on an annual basis[6]. Data for waste collection comes from the Hamburg Department of the Environment, Climate and Energy[7]. For recycling data, we rely on numbers given by Hamburg's Department of Sanitation[8] as well as by the Statistical Office[9]. Data on greenhouse gas emissions come from the Statistical Office[10]. For private consumption, data are available from the 2018 survey of consumption expenses of private households which is conducted every five years by the Statistical Office for Hamburg and Schleswig-Holstein[11]. This is the only direct data collection on consumption that is publicly available. For company consumption we use data about investments in the manufacturing sectors [12].

In addition, to give a rough breakdown of material flows for Hamburg, we use the Raw Material Consumption numbers for Germany from EUROSTAT which were calculated by the Institut für Energie und Umweltforschung ifeu (institute for energy and environmental research) in Heidelberg (Schoer et al., 2021). For ecological footprints in global hectares, we use numbers from the respective study of the Zukunftsrat Hamburg (future council of Hamburg) conducted in 2012 (Zukunftsrat, 2012).

While the data for energy, water, waste and recycling can be directly analyzed, data for production and consumption have to be matched where possible. Production data is grouped according to NACE codes, private consumption data according to COICOP codes. For this purpose, we have built a concordance table between NACE codes and COICOP codes, because we want to a) estimate what fraction of demand a sector could theoretically produce and b) weight different sectors according to the weighting scheme for the calculation of the consumer price index.

[4] The series "Energiebilanz und CO2-Bilanzen für Hamburg".
[5] Hamburg Wasser annual reports.
[6] These are mainly the statistical reports series C I 3 "Der Anbau von Gemüse und Erdbeeren in Hamburg", i.e. production of fruits and vegetables, and C III "Die Viehwirtschaft in Hamburg", i.e. livestock production, for agriculture and E I 5 "Die Produktion des Verarbeitenden Gewerbes in Hamburg", i.e. manufacturing.
[7] The series "Siedlungsabfälle in Hamburg"
[8] The series “Umwelterklärung”, the annual environmental report, and “Stadtreinigung Hamburg. Daten und Fakten”.
[9] The series Q II 4 "Erhebung über die Aufbereitung und Verwertung von Bau- und Abbruchabfällen in Hamburg" specifically for construction waste.
[10] The series "Energiebilanz und CO2-Bilanzen für Hamburg" and the series Q V 3 "Klimawirksame Stoffe in Hamburg", i.e. other climate-relevant substances.
[11] The classification of consumer expenses in this survey still follows SEA-CPI 2013. In 2021 SEA-CPI was made congruent with COICOP (Statistisches Bundesamt 2021).
[12] The series E I 6, "Investitionen im Verarbeitenden Gewerbe sowie im Bergbau und bei der Gewinnung von Steinen und Erden in Hamburg"

As Ganglmair et al. correctly note, for consumers "not all industries are equally relevant", and they have built a similar concordance table for the calculation of price markups (Ganglmair, 2020).

The weighting scheme for the consumer price index is a well-founded tool that has long been in use for measuring inflation (Statistisches Bundesamt, 2019). It reflects the relevance of groups of goods and services for consumers, that is citizens. All weights are given in per mille and add up to 1000. After matching production data with consumption data via the concordance table, only weights are used where a matching of data is possible.

These weights can be adjusted so that they add up to 1000 again, and used to calculate the index number. Hence, we could get a first estimate of a "consumption-based" Fab City Index.
The Hamburg Chamber of Commerce has provided a geographical breakdown of companies classified according to NACE categories for the seven districts of Hamburg. It allows one to identify where in the city certain sectors and subsectors are clustered. If aligned with the groups of goods for the consumer price index by use of the concordance table, one can depict how many manufacturers for a certain group of goods there are, if at all.

04 Preliminary Results

Data are evaluated for the year 2019, because it was the last year before the Sars-CoV-2 pandemic distorted the economy. It is important to understand that matching production value and consumption expenses through the concordance table can only reveal what potential production capacity there is compared to demand. The numbers do not indicate that a certain sector is manufacturing the very goods that are actually consumed in Hamburg. It indicates that there would probably be enough machinery and equipment (and expertise) to shift production to goods that would meet local demand. This matching is tenable, because production data are given in production value (that is production capacity over a year in market prices minus several taxes like alcohol tax and customs – not revenue) whereas the consumption expenses are given in household money spent (that is market prices, which have to be reduced by V.A.T). So, both data sets are market price data.

Though the project is not yet completed, some insights are already available. Some macrosectors are at a good starting point for the requirements of a circular economy, because they already show a significant capacity to match local demand:

Macro-sector 4, food and beverages, can be assigned a manufacturing capacity of roughly 50 percent of the local demand. The construction sector is quite strong, accounting for more than half of the companies registered with the chamber of commerce. This is no surprise given the intensity of construction – and demolition – projects in Hamburg.

Macro-sector 13, other goods, could meet over 60 percent of local demand if we match production value for NACE class C32 with private consumption expenses in COICOP groups 05.1, 05.4, 05.5, 05.6, 09.2, 09.3, and 09.5 (furniture, recreational goods plus groups of semi durable and durable goods for households).

Macro-sector 10, machinery and equipment, has a strong base with an annual production value of more than 2.6 billion Euro which is considerably higher than the local investments in machinery and equipment by Hamburg manufacturers in 2019.

Another strong macro-sector is 7, chemical products. The manufacturing capacity especially for pharmaceutical products is very high based on production value data. Actually, it produces more than the local demand that can be inferred from consumption data.

However, some of the macro-sectors are quite weak:

Though there are some strong players in macro-sector 12, IT and communication, these are specialized semiconductor manufacturers that don't produce consumer devices like personal computers or smartphones and could not easily switch production to these devices.

Naturally, lacking deposits within the city boundaries, macro-sector 6, fossil fuels and mining and quarrying, is more or less completely dependent on imports. The high production value for NACE division C19, manufacture of coke and refined petroleum products, of more than 1.8 billion Euro in 2019 is only possible because Hamburg as Germany's biggest port is a highly important trade center for crude petroleum.

Macro-sector 11, vehicles and transport equipment, comprises some 190 companies, but none of them is one of the big car manufacturers. The one exemption in the vehicle sector is the Airbus aircraft plant that is responsible for roughly a quarter of Hamburg's export turnover.

Macro-sectors 1 and 3, energy and agriculture/fishing, are evidently weak, because the share of renewables in energy production is still low, while agricultural land is in short supply. Compared to the area of 9.1 million global hectares needed to feed a population of 1,84 million (Zukunftsrat, 2012), the land area used by agriculture is less than 15,000 hectares. Figure 1 shows a summary of the preliminary results.

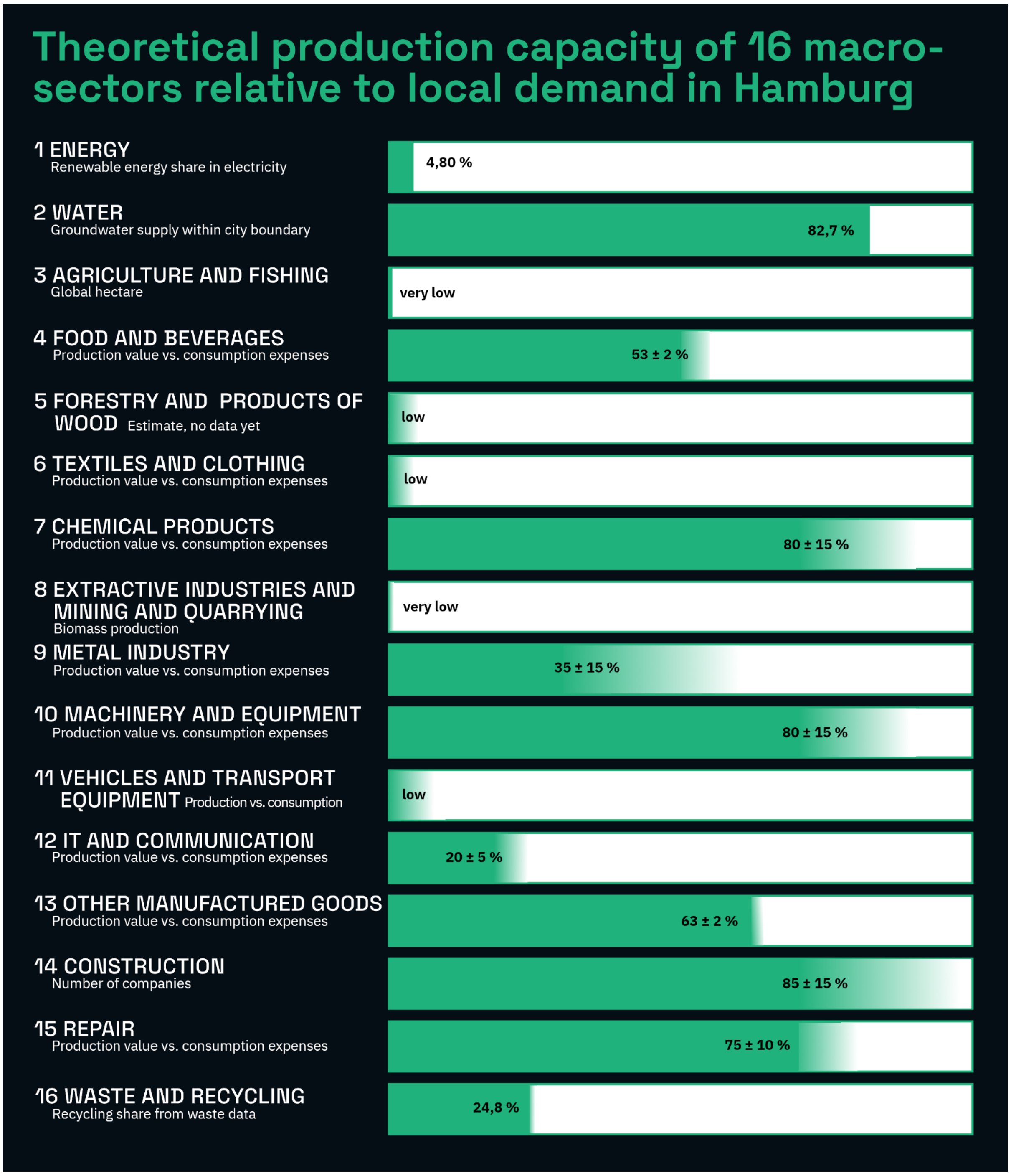

Fig. 1. Each macro-sector has a bar that runs from 0 percent to 100 percent local production capacity. The blurring of the actual preliminary value indicates the uncertainty of that value for the moment.

Now that we have preliminary self-sufficiency levels for each macro-sector, we have to assign them weighting factors. For some macro-sectors we can use the weighting factors from the consumer price index where consumption expenses have been recorded. For others we rely so far on an informed guess. Tab. 2 shows the weighting factors that could be used for a first calculation of the index number.

Tab. 2. Weightings in the fourth column come from weightings of consumption expense categories that were applicable for the calculation. Weightings in the fifth column are estimates for sectors, where no consumption data are available yet. Weights in both columns are given in per mille and add up to 1000.

	Ratio production/consumption	Basis of ratio	Weighting according to CPI schem, if applicable, in ‰	Weighting estimate in ‰	Weighted rates	NACE / WZ2008 divisions	Note
Energy (renewable)	4,80 %	Mwh/TJ	68,82		0,0033	(D35)	Weighting from COICOP 04.5
Water	82,70 %	Groundwater supply	36,43		0,0301	(E36)	Weighting from COICOP 04.4
Agriculture and fishing	0,05 %	Global hectares		96,85	0,0000	A01, A03	Weighting estimate from COICOP 01
Food and beverages	53,87 %	Production value vs. consumption expenses	134,62		0,0725	C10, C11	Weighting from COICOP 01 and 02
Wood and products of wood	5,00 %	Estimate		27,08	0,0014	A02, C16, C18.1	Weighting estimate, includes COICOP 09.7
Textiles and clothing	0,42 %	Production value vs. consumption expenses	49,29		0,0002	C13, C14, C15	Weighting from COICOP 03 and 05.2
Chemical products	90,00 %	Estimate from production value vs. consumption expenses	46,13		0,0415	C19, C20, C21, C22	Weighting from COICOP 06
Fossil fuels, mining and quarrying	0,05 %	Biomass production, no deposits		30,00	0,0000	B5, B6, B7, B8	Weighting estimate
Metals	50,00 %	Estimate from production value vs. consumption expenses	74,25		0,0371	C24, C25	Weighting from COICOP 13
Machinery and equipment	90,00 %	Estimate from production value vs. consumption expenses		74,25	0,0668	C27, C28	Weighting from COICOP 13
Vehicles and transport equipment	1,00 %	Estimate from production value vs. consumption expenses	129,05		0,0013	C29, C30	Weighting from COICOP 07
IT and communication	20,00 %	Estimate from production value vs. consumption expenses	47,54		0,0095	C26, C18.2	Weighting sums up from classes in COICOP 08
Other goods	63,41 %	Production value vs. consumption expenses	50,04		0,0317	C23, C32	Weighting from COICOP 05
Construction	100,00 %	Number of companies		37,77	0,0378	C41, C42, C43	Weighting estimate
Repair	80,00 %	Estimate from production value vs. consumption expenses	27,88		0,0223	C33, G45, S95	Weighting from COICOP 04.3 and 07.2.3
Waste and recycling	24,80 %	Recycling share from waste data		70,00	0,0174	(E37, E38, E39)	Weighting estimate
			664,05	335,95	**0,37**		

From these weighting estimates we would get a Fab City Index value for Hamburg of 37 on scale between 0 and 100. However, the weighting factors require further discussion, as we show in the next section.

05 Discussion and Outlook

Though these insights already indicate where a strategy for a circular economy should focus, they only give a coarse picture. Much more hard data is needed. The publicly available data suffer from several limitations. One is a legal restriction. Production values are collected for companies with 20 or more employees. Data for 2019 is shown for 1246 companies in the series E I 5, while there are more than 17,500 companies classified by the chamber of commerce in the NACE groups in manufacturing, albeit most of them are small-scale enterprises. Unfortunately, production value is not available for all companies considered in the series. If a NACE group features only a low single digit number of companies and one of them has a huge market share in comparison to the others, production value is not shown due to protection of competition. Otherwise, production values of the small companies could be inferred from the approximately known value of the big player. This regulation distorts the data.

Import and export data could principally help to clarify which sectors, and that is: which areas of consumption, are primarily dependent on imports. Unfortunately, transshipments in Hamburg's port distort this data. Imports are given for general trade[13], i.e., goods that are not consumed in the city, but go in stock and can stay there for an unknown time, are not excluded from the import value. On the other hand, exports are counted as special trade[14] which is goods that have been manufactured or completed in Hamburg. So, the transit of goods is not recorded, thus we cannot infer from the balance of import and export values the real balance of goods. According to the Statistisal Office this makes Hamburg an exception compared to other federated states of Germany to date.

A third limitation is the aforementioned lack of comprehensive consumption data. In the regular consumer survey, expenses are inquired only for a limited number of goods, not the entirety of goods as listed in the COICOP classification. Thus, the numbers mostly apply to aggregated classes of goods like clothing and footwear, whereas the expenses for instance for household appliances are not collected. Given that household appliances constitute an important equipment for households – though not being replaced very often –, an average number would be helpful for a circular economy strategy that takes the local manufacturing of household appliances into account.

In general, the data being collected has a bias towards a traditional industrial policy which emphasizes output and growth rates and does not explicitly take sustainability issues into account, let alone the imperative of a circular economy. With respect to the requirements of the Fab City concept, the extent and reliability of environmental data meanwhile outmatches that of economic data, which is remarkable given that economic statistics have a much longer history.

Whether the perspective of traditional industrial policy is taken or the perspective of a Fab City circular economy affects the priority of the macro-sectors which is reflected in the weighting scheme of the consumer price index. For instance, macro-sector 11, vehicles and transport equipment, currently has a high priority for the German economy in general because it is associated with jobs and exports as well as the aspiration of limitless mobility. On the consumption side its weighting factor is quite high with a value of 129,05 per mille. In the future its priority certainly has to decrease. Hamburg for instance has had a fleet of more than 950,000 vehicles – including 813,847 passenger cars – in 2021. A Fab City would not seek to constantly renew this fleet by adding thousands of cars each year. That means: The priority of a macro-sector and hence its weighting factor in the index calculation is not simply a question of statistics, but an eminently political question. It has to reflect thresholds of sustainability.

[1] German: “Generalhandel”
[1] German: “Spezialhandel”

In the case of macro-sector 11, what is the sustainability threshold for urban mobility – concerning the number of private cars and the frequency of public transport services? Should a Fab City eventually be a bicycle city where car mobility becomes a rarity such that the manufacturing of cars is of minor importance? The answers to these questions will strongly affect the priority of macro-sector 11. The same holds for other sectors.

That said, the Fab City Index concept as introduced here is only a starting point. It can serve as a framework with which first assessments of a Fab City's development are possible in the next few years, but parts of the framework can and will change over time. The priorities, that is the weighting factors of the macro-sectors, have to be constantly reviewed. Even the suggested classification of the 16 macro-sectors is not fixed once and for all. Yet without a structured framework for assessing the efforts towards a circular economy the road to the Fab City 2054 goal cannot be taken.

There is another caveat: The Fab City concept can probably not adhere to a city's territory in a strict sense. Hamburg, being a city state in Germany, has the advantage of having data available on the city level. However, in the long run the metropolitan region will probably be the more practical frame of reference. It is not only the agricultural production of the surrounding regions that Hamburg relies on and cannot substitute easily. Macro-sector 2, water, gives another example. All drinking water in Hamburg is extracted from groundwater, but the groundwater supply within the city's boundaries covers only 82.7 % of its consumption. The rest is drawn from the surroundings with which Hamburg has secured water rights. Thus, Hamburg would have to reduce its water consumption. Regarding the increasing risk of droughts even in the rainy North of Germany, a reduction alone could perhaps not be enough to keep the city's water demand and the groundwater supply in balance. How the macro-sectors will develop and if the metropolitan region has to be included, will require political decisions.

That does not change the fact that the advance of the Fab City concept should be accompanied by a refined data collection strategy. This will certainly not be implemented at short notice. However, more accurate and more relevant data would make the steps towards a fully circular economy more transparent. It could also help to spur innovation and make progress comparable across the Fab City network. Finally, it could coalesce with current efforts of some cities to implement dashboards that visualize environmental and/or smart city metrics. Fab City Hamburg e.V. plans to implement a "Fab City Dashboards" that would show key metrics as indicated above. This would not only help policymakers, but companies and the general public alike to comprehend what is needed for realizing the potential of the Fab City. Fortunately, a unified data framework at least for European cities is already at hand with NACE and COICOP classifications. More comprehensive data could support the next steps substantially.

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