

Use of Agricultural Biomass by Paper, Pharmaceutical and Biogas Industries

The material use of agricultural crops for the construction sector or production of polymers and man-made textiles occurs not directly, but through intermediate use of bio-based materials processed by the chemical industry (C20). We assume that the additional demand for agricultural crops as feedstock needed for the production of bio-based materials outside the chemicals industry (C20), is limited to the use of starch by the paper industry and the use of sugar by the pharmaceutical industry.

Use of starch by the paper industry (C17). The paper industry is an important consumer of starch and starch-based products, especially glues. Starch-based products are inputs to the paper industry from other sectors (e.g., starch-based glues are an output from the chemical industry, C20) and, therefore, the respective demand for starch is already covered by the demand from these sectors (e.g., C20). However, the paper industry also uses considerable quantities of starch as a direct input, which must be additionally considered in order to determine the total demand for material use of starch apart from the C20 industry.

There are no official statistics on the direct starch use by the paper industry in EU countries. We have analyzed different sources providing information about the use of starch by the paper industry on national and EU level, i.e. information from associations, industry reports and other publications. Unfortunately, figures vary greatly depending on the source. Comparing figures provided by associations we observed that figures reported by associations which represent the starch industry (e.g., Starch Europe [1] for the EU, VGMS [2] for Germany) are considerable higher than figures reported by associations which represent the paper industry such as Cepi [3], Verband Deutscher Papierfabriken e. V. (VDP) or DIE PAPIER-INDUSTRIE e. V. [4] in Germany (**Table S1**). For example, Starch Europe reports that 31% of 10.9 million tons of starch (2.85 million tons of starch) were used for "Corrugating & Paper" application in the EU28 in 2020. The European association representing the paper industry (Cepi) on the other hand reports that its members (17 EU28 member countries plus Norway) covering 98,3% of the total paper and board production in the EU28 (plus Norway) used only 1.69 million tons of starch for production of paper and boards in 2020 [5]. Similarly, for Germany in 2020, VGMS reports the use of 0.808 million tons of starch in paper industry whereas VDP reports only the use of 0.482 million tons of starch. Figures available from other reports and publications [6,7] are closer to the figures reported by associations which represent the paper industry than those reported by associations which represent the starch industry. While Cepi and VDP report figures on the quantities of starch used as a raw material for paper production, Starch Europe and VGMS do not specify what is included in their figures. A possible explanation could be, that figures provided by Cepi and VDP cover only the direct use of starch by the paper industry, whereas figures provided by Starch Europe and VGMS also cover the indirect use of starch in form of starch-based inputs/products (e.g., glues and coating materials). As already mentioned, the demand for starch for the production of starch-based chemicals (e.g., glues and coating materials) is calculated separately in the demand for starch by the chemical industry (C20). Therefore, we conclude that the figures provided by the paper industry associations (e.g., Cepi, VDP) on the use of starch for paper production are more suitable for our purpose. In **Table S1**, we have calculated a "Starch in Paper coefficient (SPc)" that reflects the relation between the total production quantities of pulp and paper and the quantity of starch directly used by the paper industry:

$$SPc = \text{Starch use in Paper Industry} / \text{Production of Pulp and Paper}$$

Based on data from the paper industry associations (VDP and Cepi) on starch use in the paper industry, the value of the SPc for Germany is 0.0215-0.0231 and for Cepi-members it is 0.0166-0.0198 (for "Cepi – Germany": 0.0147-0.0189). We have additionally evaluated these figures with experts. The figures for Germany based on the VDP data are in line with the experts' estimates, while the figures for the rest of Europe are considered by the experts to be somewhat low. So, in the BioMAT database we use the figures on quantities of starch used directly by the paper industry for Germany from VDP, whereas for the rest of countries we calculate these quantities using the SPc of 0.020-0.022 (linear increase over 2015-2020, in line with the calculated value for SPc based on different sources).

Table S1. Use of starch by paper industry in Germany and the EU.

	2014	2015	2016	2017	2018	2019	2020
Production of Pulp and Paper (in 1,000 tons)^{a)}							
<i>Germany</i>	22,540	22,601	22,629	22,925	22,682	22,080	21,339
<i>EU28</i>	91,883	91,505	91,342	92,664	92,586	89,937	85,329
<i>Norway</i>	1,023	979	1,099	1,097	1,134	1,155	933
<i>Cepi^{b)} (18 EU countries + Norway)^{c)}</i>	91,093	90,951	90,903	92,299	92,233	89,578	84,797
Starch use in paper industry (in 1,000 tons) based on...							
<i>VGMS for Germany^{d)}</i>	634	656	686	706	713	713	808
<i>VDP for Germany^{e)}</i>	484	493	504	527	524	489	482
<i>StarchEurope for EU28^{d), f)}</i>	n.a.	n.a.	2,697	n.a.	2,790	2,852	2,912
<i>Cepi^{b)} (18 EU countries + Norway)^{c)}</i>	1,761	1,521	1,506	1,567	1,542	1,639	1,682
"Starch in Paper coefficient (SPc)"							
<i>VGMS for Germany</i>	0.0281	0.0290	0.0303	0.0308	0.0314	0.0323	0.0379
<i>VDP for Germany</i>	0.0215	0.0218	0.0223	0.0230	0.0231	0.0222	0.0226
<i>StarchEurope for EU28</i>	n.a.	n.a.	0.0295	n.a.	0.0301	0.0317	0.0341
<i>Cepi^{b)} (18 EU countries + Norway)</i>	0.0193	0.0167	0.0166	0.0170	0.0167	0.0183	0.0198
<i>"Cepi - Germany"</i>	0.0186	0.0150	0.0147	0.0150	0.0146	0.0170	0.0189

a) FAO, forest statistics, <https://www.fao.org/faostat/en/#data/FO>

b) The National Associations of the 18 following countries are Cepi members: Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, The Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and United Kingdom

c) Cepi; <https://www.cepi.org/statistics/>

d) VGMS, <https://www.vgms.de/staerkeindustrie/presse-service/daten-fakten>

e) VDP, 2021

f) <https://starch.eu/the-european-starch-industry/>

Use of sugar by the pharmaceutical industry (C21). As official statistics on quantities of sugar used in the pharmaceutical industry are missing, we estimate these figures based on following consideration: sugar is used for the production of chemically pure sugar and also as a feedstock in fermentation processes. The production of chemically pure sugar is reported under PRODCOM code 21.10.40. We assume that figures on the production of chemically pure sugar is equivalent to the demand for sugar by this production activity. **Table S2** provides figures on the EU27 production, apparent use and trade of chemically pure sugar produced by the pharmaceutical industry. It is interesting to note that export makes up a significant share of the production of chemically pure sugar. Apparent use increases over the years in line with domestic production, while import increases to a much lesser extent.

Table S2. Production, use and trade of chemically pure sugar (PRODCOM code 21.10.40) in the EU, in 1000 tons.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Production	90.00	116.84	114.04	99.94	117.59	99.95	127.27	132.09	146.71	180.00	145.47
Import	14.10	11.77	13.84	15.51	18.39	19.11	17.46	19.16	18.41	19.35	21.44
Export	89.89	90.36	86.30	92.03	88.49	83.19	82.94	84.37	83.23	84.08	78.74
Apparent use	14.21	38.24	41.58	23.42	47.50	35.86	61.79	66.88	81.89	115.27	88.17

For the production of pharmaceutical products via fermentation, both chemically pure sugar and sugar in other forms and grades (i.e., starch-based sugars) can be used. Significant quantities of sugar are utilized, for example, for the production of such amino acids as lysine (mainly feed-grade) and glutamic acid. Both products have dedicated PRODCOM codes (21.10.20.10 for “Lysine and its esters, and salts thereof” and 21.10.20.20 for “Glutamic acid and its salts”) and official statistics provide some figures on these products, although significant gaps exist because of confidentiality issues (figures can be extracted only for EU27 with a wide uncertainty range can be extracted). Currently, the production of feed-grade lysine in the EU27 takes place only in France. The plant capacity for amino acids production in France is approximately 80,000-100,000 tons/year, which in case of lysine results in a sugar demand of ca. 145,000-180,000 tons [8,9]. **Table S3** shows the production quantities of lysine and glutamic acids (PRODCOM statistics) and the estimated demand for sugar in the EU. As already mentioned, these figures should be treated with caution, as they are calculated based on production data and there is some uncertainty not properly captured when the official statistics are compiled.

Table S3. Production of glutamic acid and lysine and estimated dedicated demand for sugar, in 1000 tons, EU27.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Production (in 1000 tons)											
Glutamic acid and its salts	2	1	1	20	210	200	120	200	210	200	140
Lysine and its esters, salts thereof	120	50	40	120	180	70	60	103	100	50	60
Conversion efficiency rate (glucose->amino acid)											
Glutamic acid and its salts	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Lysine and its esters, salts thereof	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Demand for sugar/glucose (in 1000 tons)											
Glutamic acid and its salts	3	1	2	29	300	286	171	286	300	286	200
Lysine and its esters, salts thereof	218	91	73	218	327	127	109	187	182	91	109
SUM of demand for sugar	221	92	75	247	627	413	281	472	482	377	309

Assuming that no chemically pure sugar is used as input in the production of glutamic acid and lysine, we calculate the total demand for sugar needed for the production of these three products which ranges between 400,000 and 750,000 tons in the EU27 since 2014 (the year with a significant increase in glutamic acid production).

There are many more pharmaceutical products produced using sugar as a feedstock (e.g., vitamins, antibiotics, other drugs etc.). However, the estimation of the associated additional demand for sugar requires a collection of detailed information and their processing, similarly as we have done for the chemical industry. As simplification, we use the estimated figures on the demand for sugar needed for the production of chemically pure sugar, lysine and glutamic acid as a proxy for the total sugar demand from the pharmaceutical industry. At the same time, we acknowledge that these figures reflect the lower bound of the total use of sugar in the pharmaceutical industry.

The **use of crops for energy** is mainly associated with the production of biofuels and to a much lesser extent with the production of biogas. The production of biodiesel and bioethanol is reported within the chemical industry (C20) and is therefore included in its bio-based material flow database. The production of biogas (biomethane) is reported in “Section D – Electricity, Gas, Steam and Air Conditioning supply” under code “35.21: Manufacture of gas”, outside of C20. For the production of biogas, mainly liquid manure and maize silage or other fodder crops are used; to a much lesser extent, sugar crops are used. In Europe, Germany is by far the most important producer of biogas, as two thirds of European biogas plants are located here [9]. Unfortunately, there are no statistical surveys on the use of sugar crops in biogas production, but estimates indicate that in Germany sugar beets from approximately 25,000 ha are used for biogas production [10].

To summarize, currently, the total demand for crops for material and energy use outside the chemical industry (C20) is: Approximately 1,800,000-2,000,000 tons of starch for the paper industry, at least 400,000-750,000 tons of sugar (including starch-based sugar) for the pharmaceutical industry and about 280,000 tons of sugar for biogas production.

References

1. The European Starch Industry Association. Available online: <https://starch.eu/>.
2. Verband der Getreide-, Mühlen- und Stärkewirtschaft VGMS e.V. Available online: <https://www.vgms.de/>.
3. Confederation of European Paper Industries. Capi. Available online: <https://www.cepi.org/>.
4. DIE PAPIERINDUSTRIE e. V. Available online: <https://www.papierindustrie.de/>.
5. CEPI. Key Statistics 2020: European pulp & paper industry, 2021. Available online: <https://www.cepi.org/statistics/>.
6. BIO-TIC team. Material Use of Starch and Sugar in Europe 2013. Available online: <https://renewable-carbon.eu/publications/product/a-roadmap-to-a-thriving-industrial-biotechnology-sector-in-europe-%E2%88%92-poster-material-use-of-starch-and-sugar-in-europe-2013/>.
7. LMC. Global markets for starch 2020, 2021.
8. Sturm, V.; Banse, M.; Salamon, P. The role of feed-grade amino acids in the bioeconomy: Contribution from production activities and use in animal feed. *Cleaner Environmental Systems* 2022, 4, 100073, doi:10.1016/j.cesys.2022.100073.
9. IEA. Outlook for biogas and biomethane: Prospects for organic growth, IEA, Paris, 2020. Available online: <https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth>.
10. BLE. Bericht zur Markt- und Versorgungslage Zucker, 2022. Available online: https://www.ble.de/SharedDocs/Downloads/DE/BZL/Daten-Berichte/Zucker/2022BerichtZucker.pdf?__blob=publicationFile&v=2.