**Methodological appendix: reconstructing the industrial energy consumption**

The method behind the reconstruction of industrial fuel consumption is largely based on Cavert who studied industrial coal consumption in early modern London.[[1]](#footnote-1) Cavert used production data of various industries (brewing, distilling, sugar refinery, brick making, lime burning and glass making) to estimate each of these industries fuel needs. Here, I have distinguished between eleven fuel-consuming industries:

* 1. Bleaching and dyeing of textiles;
  2. Brewing;
  3. Baking;
  4. Distilling;
  5. Salt refinery (only in Ghent);
  6. Sugar refinery (only in Ghent);
  7. Brick and lime making;
  8. Soap boiling;
  9. Glass making;
  10. Pottery;
  11. And the use of steam engines across various industries.

The production data of the selected industries were obtained on the basis of taxes levied on the involved industries’ products, either at the manufacturing or retailing stage. For those products that were only taxed when they were sold on the city market, no direct production figures could be supplied. Indeed, the data on brewing (only in Ghent), baking, distilling, salt refining and soap boiling relate to urban consumption volumes, regardless of where the production actually took place. In those cases I have assumed that all the beer, bread, brandy, salt or soap consumed in the city was also produced in the city – which of course, considering the import of goods into the city, accounts for an overestimation of the energy consumed by the urban industries behind these products. Since they produced staple goods, it can, however, be assumed that most of these industries were located within the city itself – or at least within its close vicinity –, so the overestimations should be limited.

The list of industries above is by no means an exhaustive list. Metal smelting and working, for instance, were also industrial processes that required much heat energy. While smithying was certainly present in Ghent and Leiden, its exclusion is an unfortunate result of a lack of data, as the production of metal processing trades was left untaxed by the urban government. And even though the administrative decisions of city governments to levy or not to levy taxes on industrial production were not arbitrary – most likely indicating that blacksmiths were of only marginal importance in early modern and nineteenth-century Ghent and Leiden – a certain quantity of industrial energy consumption still remains unrepresented. Therefore, the estimations presented in this article account for a minimal amount of the total energy consumed by industry in the two cities under scrutiny.

Besides the problem of production data vs. consumption data and the inevitable dark number behind untaxed industry, a final major methodological flaw relates to determining the energy requirements per unit of production. Indeed, the energy volumes consumed by industry are calculated here by multiplying the production figures by a fixed ratio of fuel energy needed to make one product (a piece of bleached linen, a ton of sugar or a barrel of beer, for example). Since, in the absence of good account books from tradesmen, there are few indications of how much fuel producers budgeted for per product that they manufactured. The energy values used are necessarily derived from very rare cases (mostly from Britain and France) that were studied in the margin of historiography. This methodology does, of course, overlook the variations in energy efficiency between cities and regions as well as those that varied over time. Notwithstanding the abundance of literature on the history of technology, there is a remarkable historiographical silence on fuel-burning technology before the invention of the steam engine. What the current literature does tell us, is that, when there was technological change, it spread rapidly across borders and that technology has always been ‘transnational’.[[2]](#footnote-2) Much of the skill and knowledge in textile bleaching and dyeing came from immigrants from Flanders and Brabant who fled to England, France and Holland in the late Middle Ages and sixteenth century;[[3]](#footnote-3) glass manufacture in the early modern Low Countries was mostly based on English technology;[[4]](#footnote-4) except for the introduction of iron and copper kettles, technical changes in brewing were slow and subtle all over early modern Northwest Europe;[[5]](#footnote-5) Boulton & Watt steam engines rapidly found their way from Britain to the Continent in the early nineteenth century – to name but a few examples.[[6]](#footnote-6) If we can build further on observations such as these, the exportation of energy/output ratios from one region to the other should not be entirely problematic.

To be sure, the energy requirements per unit of output refer only to the fuel that was spent inside the workshop itself from the moment it arrived there. The energy needed for the transport and production of the fuels consumed is not included (which would attest for the total energy intensity of an economy – that is, the ratio of energy units per unit of GDP). Regional differences were mostly located in the broader energy system, in which fuel supplies and fuel demands came together. In this article, I am only interested in the demand for fuel by the industry, not in the supply of fuel for the industry. The latter – in the form of the regional divergences in the Low Countries’ energy regime and its prices – will serve as a framework to assess whether or not these divergences also translated into divergent levels of industrial energy consumption.

The specific calculations and their references per industry are given below

1. 1. **Bleaching and dyeing**

During the long eighteenth century Ghent was a centre for the bleaching of linen textiles which were mostly produced in the countryside and subsequently traded on the market by urban entrepreneurs.[[7]](#footnote-7) Leiden at that time was renowned for its vibrantly coloured dyed cloth.[[8]](#footnote-8) In both towns, the volume of textiles sold on the urban market had to be registered first by the city government which raised taxes on each piece. I have assumed that all linen and woollen textiles sold on the Ghent and Leiden markets, respectively, were bleached or dyed. Since this certainly was not the case, the figures for the fuel needs of the bleaching and dyeing sectors are undoubtedly overestimated. A study of fuel saving in British process industries in the eighteenth and nineteenth centuries has found that each bleaching or dyeing vessel daily required about half a ton of coal (i.e. 13.5 GJ of energy).[[9]](#footnote-9) Assuming that each dyer in Leiden had one vessel at his disposal and knowing that each dyer produced about five units per day, each piece of dyed cloth must have taken about 2.7 GJ of energy.[[10]](#footnote-10) In Ghent, master bleachers produced about eight pieces a day; hence, each unit of production required about 1.7 GJ.[[11]](#footnote-11)

* 1. **Brewing**

Production data on brewing are available for Leiden.[[12]](#footnote-12) For Ghent I have used consumption data – assuming that all beer drunk in the city was also produced in the city.[[13]](#footnote-13) According to Cavert, a barrel of beer required an average amount of 20 kg of coal – corresponding to about 3.4 MJ per litre of beer.[[14]](#footnote-14)

* 1. **Baking**

Baking data for both Ghent and Leiden were derived from consumption instead of production figures.[[15]](#footnote-15) Since the bread produced by urban bakers was mostly – if not all – directed at local customers, consumption figures are most likely to have closely followed production figures. According to Steven L. Kaplan, it took about two pounds of wood to turn a *setier* (= 152 litres / 95 kg) of wheat into bread.[[16]](#footnote-16) This means that it required about 0.26 GJ of energy to bake a ton of bread.

* 1. **Distilling**

Distilling was based on the consumption of brandy.[[17]](#footnote-17) In early modern London it took about 11,200 tons of coal to produce 4 million gallons of gin. This would translate into about 16.8 MJ per litre of distilled liquor.[[18]](#footnote-18)

* 1. **Sugar refining**

Sugar refining started to develop in Ghent from the middle of the eighteenth century onwards, but was absent from Leiden. The data are based on two benchmarks only: 1764 (used as an indicative figure for 1750) and 1804 (used for 1800). In 1764 the Austrian government took an industrial survey in all districts of the Southern Low Countries, reporting on an output of 217 tons of sugar by Ghent’s only sugar refinery.[[19]](#footnote-19) In 1804, when the French prefect Faipoult undertook a similar survey on behalf of the French government, he noticed that the number of refineries in Ghent had risen to 13, producing a combined total of 2,821 tons of sugar.[[20]](#footnote-20) A study on the French sugar industry in the eighteenth century has found that it required about 1.1 tons of coal to make 1 ton of refined sugar; or, 29.7 GJ per ton.[[21]](#footnote-21)

* 1. **Salt refining**

Although Holland is known to have produced substantial amounts of salt – mostly directed at the needs of the herring sector – no such trade was found in Leiden.[[22]](#footnote-22) Ghent, on the other hand, had developed a salt refining industry during the early modern period. Again, the data are based on consumption levels.[[23]](#footnote-23) At least from the industrial survey of 1764 we know that the actual output of Ghent’s single salt refinery was around 800 tons, which seems to have corresponded rather well with the total consumption of salt in the city: around that time it reached a level of almost 600 tons annually.[[24]](#footnote-24) This suggests that most salt produced in Ghent was also sold and consumed in the city itself. I have used the same ratio of energy input per economic output as for sugar refining.

* 1. **Brick and lime making**

Brick and lime were used in the building sector. In Ghent the use of bricks was subject to a tax.[[25]](#footnote-25) I have assumed that all these bricks were produced in (and thus required their energy from within) the city. For Leiden I have used the data provided by de Vries and van der Woude on the number of brick and lime kilns in Holland and the estimated number of bricks they produced annually.[[26]](#footnote-26) I have adjusted these figures for Leiden on the basis of demographic distribution. Limekilns could be found in Leiden from the sixteenth century on, although most of them were probably located in the surrounding countryside just outside the city.[[27]](#footnote-27) Cavert has suggested that the production of 100 million bricks cost about 14,000 tons of coal.[[28]](#footnote-28) This means that it required c. 3.8 MJ of energy to fire one brick.

* 1. **Soap boiling**

Both Leiden and Ghent produced soap.[[29]](#footnote-29) The data behind soap boiling are again, however, based on consumption estimates.[[30]](#footnote-30) A study of soapmaking in nineteenth-century Britain reckoned that the production of 1 ton of soap required about 1 ton of coal or 27 GJ of energy.[[31]](#footnote-31)

* 1. **Glass making**

A guild of glass makers existed in Leiden from 1618 until 1812. In Ghent, the glass industry developed quickly in the seventeenth century, but had already disappeared before the close of the eighteenth century. Glass makers in both towns mostly produced bottles, but occasionally also fabricated window glasses and mirrors.[[32]](#footnote-32) Eleanor Godfrey’s study of English glass making estimated that it took 6 tons of coal (or 162 GJ of energy) to make 1 ton of glass.[[33]](#footnote-33)

* 1. **Pottery**

While Delft was famous for its majolica production during the early modern period, other Dutch cities such as Leiden had pottery industries as well. The city is known to have had five potteries in 1674.[[34]](#footnote-34) In Ghent there were five potteries in 1738, and the city probably had about seven to eight pottery workshops in the sixteenth and seventeenth centuries.[[35]](#footnote-35) By 1764 there was only one pottery left.[[36]](#footnote-36) Pottery production estimates were based on Lorna Weatherill’s study of the pottery industry in early modern England, which found that one workshop produced about 100,000 pieces a year and that it took about 14 tons of coal to do so.[[37]](#footnote-37)

* 1. **Steam**

A crucial development in the industrial consumption of energy happened, of course, when the steam engine was introduced. It allowed one to convert heat energy into mechanical energy. Work that was usually done by human or animal labour could now be performed by means of burning coal. Machine-driven production obviously made the industry more energy- and capital-intensive. Both in Leiden and Ghent the steam engine found its way into several industrial sectors from the end of the eighteenth and early nineteenth centuries onwards, especially in the textile industry. Steam was used in Ghent in cotton spinning, calico printing and cotton weaving.[[38]](#footnote-38) In Leiden engines were mostly deployed for the production of woven cloth and other woollen textiles.[[39]](#footnote-39) But other industries adopted this new invention as well: engines could be found in distilleries, metal-working factories and oil-producing companies. The number of steam engines in both cities during the nineteenth century was counted.[[40]](#footnote-40) Fuel requirements per engine per year were based on the estimates of von Tunzelmann who calculated that one steam engine annually consumed 22 tons of coal per horsepower – assuming that each engine had an average power of 16 hp.[[41]](#footnote-41)

1. Cavert, ‘Industrial coal consumption’. [↑](#footnote-ref-1)
2. This is amply shown in Davids, *The Rise and Decline* in his highly comparative case on Dutch technological leadership. [↑](#footnote-ref-2)
3. Bart Lambert and Milan Pajic, ‘Drapery in exile: Edward III, Cochester and the Flemings, 1351-1367’, *History*, 99:5 (2014), 733-753; J. Briels, *Zuidnederlandse immigratie, 1572-1630* (Haarlem, 1978). [↑](#footnote-ref-3)
4. Kerssies, ‘Het geheim van de Engelse glasoven’. [↑](#footnote-ref-4)
5. Most notably, knowledge in beer production spread from continental Europe (the Low Countries in particular) to England during the late Middle Ages: Milan Pajic, ‘“Ale for an Englishman is a natural drink”: the Dutch and the origins of beer brewing in late medieval England’, *Journal of Medieval History*, 45:3 (2019), 285-300; Unger, *A History of Brewing in Holland*, 108-110. [↑](#footnote-ref-5)
6. Jennifer Tann and M.J. Breckin, ‘The international diffusion of the Watt engine, 1775-1825’, *The Economic History Review*, 31:4 (1978), 541-564. [↑](#footnote-ref-6)
7. Linen production data were derived from Rudy Van Daele, ‘Proeve tot een sociaal-economische studie van Gent op basis van de accijnsrekeningen (17de-18de eeuw)’,University of Ghent MA thesis, 1985, 152-157; and Sabbe, *De Belgische vlasnijverheid*, II, 630. [↑](#footnote-ref-7)
8. Cloth production data were derived from Posthumus, *De geschiedenis van de Leidsche lakenindustrie*, III, 930-931, 1098-1099. [↑](#footnote-ref-8)
9. Jennifer Tann, ‘Fuel saving in the process industries during the industrial revolution: a study in technological diffusion’, *Business History*, 15:2 (1973), 157. [↑](#footnote-ref-9)
10. Posthumus, *De geschiedenis van de Leidsche lakenindustrie*. [↑](#footnote-ref-10)
11. Sabbe, *De Belgische vlasnijverheid*. [↑](#footnote-ref-11)
12. Unger, *A History of Brewing in Holland*, 239. [↑](#footnote-ref-12)
13. Van Daele, ‘Proeve’, 33-59; Chris Vandenbroeke, ‘Voedingstoestanden te Gent tijdens de eerste helft van de 19de eeuw’, *Belgisch Tijdschrift voor Nieuwste Geschiedenis*, 1 (1973), 147. [↑](#footnote-ref-13)
14. Cavert, ‘Industrial coal consumption’, 430. [↑](#footnote-ref-14)
15. Ghent: Van Daele, ‘Proeve’, 19-27; Vandenbroeke, ‘Voedingstoestanden te Gent’, 143. Leiden: RAL, City Archives of Leiden II, rekeningen van de tresorier ordinaris, nos. 7475-7516; RAL, City Archives of Leiden II, blaffaards van de tresorier ordinaris, nos. 9722-10095; RAL, City Archives of Leiden III, city accounts, nos. 3486-3533. [↑](#footnote-ref-15)
16. Kaplan, *The Bakers of Paris*, 77. [↑](#footnote-ref-16)
17. Ghent: Van Daele, ‘Proeve’, 62-70; Vandenbroeke, ‘Voedingstoestanden te Gent’, 148. Leiden: RAL, City Archives of Leiden II, rekeningen van de tresorier ordinaris, nos. 7475-7516; RAL, City Archives of Leiden II, blaffaards van de tresorier ordinaris, nos. 9722-10095; RAL, City Archives of Leiden III, city accounts, nos. 3486-3533. [↑](#footnote-ref-17)
18. Cavert, ‘Industrial coal consumption’, 431. [↑](#footnote-ref-18)
19. Philippe Moureaux, *La statistique industrielle dans les Pays-Bas autrichiens à l’époque de Marie-Thérèse: documents et cartes* (Brussels, 1974-1981), 325. [↑](#footnote-ref-19)
20. Faipoult, *Mémoire statistique*, 175 [↑](#footnote-ref-20)
21. Stein, *The French Sugar Business*, 132. [↑](#footnote-ref-21)
22. de Vries and van der Woude, *The First Modern Economy*, 419-420. [↑](#footnote-ref-22)
23. Van Daele, ‘Proeve’, 91-99. [↑](#footnote-ref-23)
24. Moureaux, *La statistique industrielle*, 324-325. [↑](#footnote-ref-24)
25. Van Daele, ‘Proeve’, 121-128. [↑](#footnote-ref-25)
26. de Vries and van der Woude, *The First Modern Economy*, 304-305. [↑](#footnote-ref-26)
27. Bas van Bavel, ‘Early proto-industrialization in the Low Countries? The importance and nature of market-oriented and non-agricultural activities on the countryside of Flanders and Holland’, *Revue Belge de Philologie et d’Histoire*, 81 (2003), 1136. [↑](#footnote-ref-27)
28. Cavert, ‘Industrial coal consumption’, 434. [↑](#footnote-ref-28)
29. In Ghent soap and soda production was closely related to the salt industry: Deseijn, ‘Zoutproductie in Gent’. Leiden: *Berigten over het fabrijkwezen in het jaar 1857* (Haarlem, 1857); Jan Luiten van Zanden, ‘De economie van Holland in de periode 1650-1805. Groei of achteruitgang? Een overzicht van bronnen, problemen en resultaten’, *BMGN – Low Countries Historical Review*, 102:4 (1987), 594-595. [↑](#footnote-ref-29)
30. Ghent: Van Daele, ‘Proeve’, 164-168. Leiden: RAL, City Archives of Leiden II, rekeningen van de tresorier ordinaris, nos. 7475-7516; RAL, City Archives of Leiden II, blaffaards van de tresorier ordinaris, nos. 9722-10095; RAL, City Archives of LeidenIII, city accounts, nos. 3486-3533. [↑](#footnote-ref-30)
31. L. Gittins, ‘Soapmaking in Britain, 1824-1851: a study in industrial location’, *Journal of Historical Geography*, 8:1 (1982), 34. [↑](#footnote-ref-31)
32. Data were derived from Van Heesvelde, ‘De glasnijverheid te Gent’ (Ghent) and RAL, Index Gilden, namen van meesters, leerlingen enz. 1574-1812; Klein, ‘Nederlandse glasmakerijen’ (Leiden). [↑](#footnote-ref-32)
33. Godfrey, *The Development of English Glassmaking*, 194. [↑](#footnote-ref-33)
34. Marie-Cornélie Roodenburg, *De Delftse pottenbakkersnering in de gouden eeuw (1575-1675). De produktie van rood pottengoed* (Hilversum, 1993), 123. [↑](#footnote-ref-34)
35. Johan Dambruyne, *Corporatieve middengroepen: aspiraties, relaties en transformaties in de 16de-eeuwse Gentse ambachtswereld* (Gent, 2002), 44, 755. [↑](#footnote-ref-35)
36. Moureaux, *La satistique industrielle*, 321. [↑](#footnote-ref-36)
37. Lorna Weatherill, *The Growth of the Pottery Industry in England, 1660-1815* (New York, 1986), 440-441, 452. [↑](#footnote-ref-37)
38. Coppejans-Desmedt, ‘De Gentse textielnijverheid’, 175 ff. [↑](#footnote-ref-38)
39. Smit, ‘De introductie van de stoomkracht’, 527-535. [↑](#footnote-ref-39)
40. Van Neck, *Les débuts*, 824-827; Smit, ‘De introductie van de stoomkracht’, 529. [↑](#footnote-ref-40)
41. G.N. von Tunzelmann, *Steam Power and British Industrialization to 1860* (Oxford, 1978), 67-70. [↑](#footnote-ref-41)