Industrial energy consumption in the urban Low Countries: Ghent and Leiden compared (c. 1650-1850)

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The importance of fossil energy in history is the subject of ongoing debate, especially among economic historians working on the industrial revolution.[1] Indeed, energy has been placed by historians at the heart of the industrialisation process in eighteenth- and nineteenth-century Northwest Europe. After a first wave of publications that appeared in the wake of the oil crisis during the 1970s, various scholars have searched for the importance of energy transitions in processes of historical development.[2] Expanding on earlier ideas produced by Phyllis Deane, David Landes and Fernand Braudel, among others, and building on the empirical evidence of John U. Nef on the British coal industry, E.A. Wrigley, in particular, has fundamentally shaped the early modern history of energy.[3] According to Wrigley, an energy revolution to the use of fossil fuels played a pivotal role in generating modern economic growth.[4] By pointing to the importance of England's early embrace of coal, he has argued that the shift from an 'organic economy' to a 'mineral economy' was a crucial precondition for the happening of the industrial revolution. Contrary to the *flow* of energy captured in food and firewood as the most important sources of energy in organic economies, fossil fuels supplied a *stock* of energy accumulated in underground stores of minerals. In traditional energy systems growth was kept in check by the natural limits to the available land, generated by plant photosynthesis – as

[1] For an overview of energy in history see Astrid Kander, Paul Warde and Paolo Malanima, *Power to the People: Energy in Europe over the Last Five Centuries* (Princeton, NJ: Princeton University Press, 2013); Alfred W. Crosby, *Children of the Sun: A History of Humanity's Unappeasable Appetite for Energy* (New York: Norton, 2006); Roger Fouquet, *Heat, Power and Light: Revolutions in Energy Services* (Cheltenham: Edward Elgar, 2008); Vaclav Smil, *Energy and Civilization: A History* (Cambridge, MA: MIT Press, 2017).

[2] See, for instance, J.W. De Zeeuw, "Peat and the Dutch Golden Age The historical meaning of energy-attainability", *AAG Bijdragen* 21 (1978), 3-31; Richard W. Unger, "Energy sources for the Dutch Golden Age: peat, wind, and coal", *Research in Economic History* 9 (1984), 221-253; Paul Bairoch, "Énergie et révolution industrielle: nouvelles perspectives", *Revue de l'Énergie* 356 (1983), 399-409; Brinley Thomas, "Was there an energy crisis in Great Britain in the 17th century?", *Explorations in Economic History* 23:2 (1986), 124-152; Jean-Claude Debeir, Jean-Paul Deléage and Daniel Hémery, *Les servitudes de la puissance: une histoire de l'énergie* (Paris: Flammarion, 1986); Chris Vandenbroeke, "Zuinig stoken. Brandstofverbruik en brandstofprijzen in België en Frankrijk sinds de 15e eeuw", *Economisch- en Sociaal-Historisch Jaarboek* 51 (1988), 93-125.

[3] Phyllis Deane, *The First Industrial Revolution* (Cambridge: Cambridge University Press, 1965); David S. Landes, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present* (Cambridge: Cambridge University Press, 1969); Fernand Braudel, *Civilization and Capitalism, 15th-18th Century. Volume I: The Structures of Everyday Life* (London: Collins, 1985); John U. Nef, *The Rise of the British Coal Industry* (London: Routledge, 1932).

[4] E.A. Wrigley, *Continuity, Chance and Change: The Character of the Industrial Revolution in England* (Cambridge: Cambridge University Press, 1988); idem, *Energy and the English Industrial Revolution* (Cambridge: Cambridge University Press, 2010); idem, *The Path to Sustained Growth: England's Transition from an Organic Economy to an Industrial Revolution* (Cambridge: Cambridge University Press, 2016). More recently, this view has inspired many historians to search for quantitative evidence that supports the primacy of coal in the industrial revolution. See for instance Alan Fernihough and Kevin H. O'Rourke, "Coal and the European industrial revolution", *The Economic Journal* 131 (2020), 1135-1149.

farmers fetched the needed energy from the fields and forests available to them in their immediate environment. Eventually, coal (and later gas and oil as well) would allow the constraints on economic growth to be alleviated, paving the way for an industrial society to follow a 'path of sustained growth'. Although the idea that coal mattered primarily, if not only, has been questioned by various historians – most notably perhaps by Deirdre McCloskey and Joel Mokyr who argued for the cultural origins of the industrial revolution[5] – the resource-intensive view of industrialisation has proven highly influential in the debate on the rise of the west and the great divergence.[6] In this respect, it has crucially provided further scholarly material to revise the old Eurocentric narrative on the industrial revolution – establishing the importance of 'chance' in the making of economic success and re-interpreting Europe's exceptionalism as the story of a 'fortunate freak'.[7]

Yet, the historical debate on energy has its own paradigmatic obstacles to be overcome. Much of this historiography is firmly rooted in a neoclassical-economic terminology. Such a perspective departs from the idea of structural poverty as the 'normal state of affairs' in history which could eventually be overcome by an energy revolution to fossil fuels. Carlo M. Cipolla, for instance, did not hesitate to put energy forward as the most important 'limiting factor' that jeopardised economic progress in the pre-industrial period.[8] Although not sufficient in itself, coal, as a source of ecological relief, formed the 'logical' remedy for traditional Malthusian problems of scarcity, providing the necessary means for the economy to pursue Smithian growth. In this 'ecological model of economic development', as Richard G. Wilkinson attempted to reconstruct, the industrial revolution becomes not much more than a happy accident of geography in which cheap and abundant energy in the form of coal gave traditional economies the crucial spark 'from the outside' to industrialise.[9] Over the years, it is this view in particular that has been developed in more quantitative terms by a group of energy historians producing detailed empirical research on the historical changes in energy consumption – ranging from the 'miracle economies' of England and Wales to countries such

[5] Deirdre N. McCloskey, *Bourgeois Dignity: Why Economics Can't Explain the Modern World* (Chicago: University of Chicago Press, 2010); Joel Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress* (New York: Oxford University Press, 1990).

[6] Kenneth Pomeranz, *The Great Divergence: China, Europe, and the Making of the Modern World Economy* (Princeton, NJ: Princeton University Press, 2000); Robert C. Allen, *The British Industrial Revolution in Global Perspective* (Cambridge: Cambridge University Press, 2009). A contrasting view in Peer Vries, "Are coal and colonies really crucial? Kenneth Pomeranz and the Great Divergence", *Journal of World History*, 12:2 (2001), 407-446; and Gregory Clark and David Jacks, "Coal and the industrial revolution 1700-1869", *European Review of Economic History*, 11 (2007), 39-74.

[7] Wrigley, *Continuity, Chance and Change*; Pomeranz, *The Great Divergence*.

[8] Carlo M. Cipolla, *The Economic History of World Population* (Harmondsworth: Penguin, 1962); idem, *Before the Industrial Revolution: European Society and Economy, 1000-1700* (London: Methuen, 1976), 228-230. For a more recent contribution on the 'limiting factor' of pre-industrial economies, see Paolo Malanima, "The limiting factor: energy, growth, and divergence, 1820-1913", *The Economic History Review* 73:2 (2020), 486-512.

[9] Richard G. Wilkinson, *Poverty and Progress: An Ecological Model of Economic Development* (London: Methuen, 1973).

as Sweden, Italy, Portugal, Spain, Canada and the Netherlands that industrialised relatively late.[10]

Can energy ever be an autonomous explanation by itself, however? This is an issue that has been addressed by energy historians themselves. In his 'high wages, cheap energy' model of the British industrial revolution, Robert C. Allen emphasised the role of coal as a labour-saving, rather than land-saving technology.[11] The unique combination of high wages and cheap energy prices created the inventive for British industrial entrepreneurs to replace labour with capital in the form of coal-powered machinery. Building further on the importance of coal as a labour-augmenting resource, Paolo Malanima viewed the coal revolution as a two-phased transition.[12] While coal initially helped to augment the pressure on land during the seventeenth and eighteenth centuries, it is only in a later phase that it enabled the British economy to realise substantial economic growth, when coal, through scientific, institutional and social development, could be used as a substitute for labour as well. While these models do provide new clues on the chronology of England's coal transition – explaining why it utilised only by the later eighteenth century what for all that time has been under its nose – they still consider fossil energy as the main determining factor of the industrial revolution. For Malanima and Allen, the availability of coal primarily explains why England industrialised and why Italy (among other European countries) did not.[13] Looking at energy endowments to understand economic progress implies that the constraints that prevented growth were 'external' to the economy itself and that coal was an 'exogenous' *deus ex machina* that helped to escape the Malthusian trap.

Such an interpretation of the historical relationship between energy and industrialisation neglects the role of the 'internal' dynamics of social and economic development. In recent years, mostly as a result of the ecological challenges in present society, historians and social

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[10] Paolo Malanima, *Energy Consumption in Italy in the 19th and 20th Centuries: A Statistical Outline* (Naples: Consiglio Nazionale delle Ricerche, 2006); Paul Warde, *Energy Consumption in England and Wales, 1560-2000* (Naples: Consiglio Nazionale delle Ricerche, 2007); Ben Gales et al., "North versus South: energy transition and energy intensity in Europe over 200 years", *European Review of Economic History* 2 (2007), 219-253; Sofia Teives Henriques, *Energy Consumption in Portugal, 1856-2006* (Naples: Consiglio Nazionale delle Ricerche, 2009); Astrid Kander, *Economic Growth, Energy Consumption and CO2 Emissions in Sweden, 1800-2000* (unpublished PhD thesis, University of Lund, 2002); Richard W. Unger and John Thistle, *Energy Consumption in Canada in the 19th and 20th Centuries: A Statistical Outline* (Naples: Consiglio Nazionale delle Ricerche, 2013); Ruth W. Sandwell (ed.), *Powering up Canada: A History of Power, Fuel, and Energy from 1600* (Montreal: Mc Gill-Gueen's University Press, 2016); Jones, *Routes of Power*; Hana Nielsen, *Coal, Commerce and Communism: Empirical Studies on Energy History in the Czech Republic* (unpublished PhD thesis, University of Lund, 2017); H.N.M. Hölsgens, *Energy Transitions in the Netherlands: Sustainability Challenges in a Historical and Comparative Perspective* (unpublished PhD thesis, University of Groningen, 2016).

[11] Allen, *The British Industrial Revolution*.

[12] Paolo Malanima, "Energy consumption in England and Italy, 1560-1913. Two pathways toward energy transition", *The Economic History Review* 69:1 (2016), 78-103. See also Paolo Malanima, "The energy basis for early modern growth, 1650-1820", in *Early Modern Capitalism: Economic and Social Change in Europe, 1400-1800*, edited by Maarten Prak (London-New York: Routledge, 2001), 51-68; Paolo Malanima, "Energy crisis and growth 1650-1850: the European deviation in a comparative perspective", *Journal of Global History* 1 (2006), 101-121; Paolo Malanima, *Pre-Modern European Economy. One Thousand Years (10th-19th Centuries)* (Leiden: Brill, 2009), 49 ff.

[13] Malanima, "Energy consumption in England and Italy"; Robert C. Allen, "Why the industrial revolution was British: commerce, induced invention, and the scientific revolution", *The Economic History Review* 64 (2011), 357-384.

scientists have adopted a more holistic point of view to emphasise the historical interconnectedness between 'energy', 'economy' and 'society'.[14] Pioneering in writing an environmental history of coal based on the case of nineteenth-century Manchester, Stephen Mosley has shown that the rise of a fossil economy closely interacted with the social fabric of the city.[15] The dialectic relation between energy (or nature, more broadly) and society is also stressed in the concept of 'social metabolism' – a notion that was first applied to society by Karl Marx and that has since been elaborated in social ecology especially.[16] Departing from this concept, Marina Fisher-Kowalski, Fridolin Krausmann, Sabine Barles and Dieter Schott, among others, have illustrated how economies were not the mere result of their endowments in natural resources, but how they also co-produced ecological hinterlands of their own.[17] In so doing, societies have constantly alerted and expanded their ecological frontiers. In a similar but more theoretical (and explicit eco-Marxist) vein, Jason W. Moore argued how 'world-ecologies' have acted as ways of organising the physical environment according to which energy and other 'natures' (including labour, food and raw materials) were put to work usefully within an economic system.[18] Rather than interpreting coal as a 'geographic accident' happening *outside* the economy, these new approaches of research have sought the origins of the fossil economy *in* the structures of society itself.

In this paper I wish to make a modest contribution to the debate on the transition to fossil fuels and how they facilitated industrialisation, by providing a comparative analysis of the industrial energy consumption during the 'long' eighteenth century (c. 1650-1850) in Leiden and Ghent, two major textile centres in the Northern and Southern Low Countries, respectively. The Low Countries offer a curious case in the history of energy. As one of the most economically developed and urbanised regions of Europe, it has been credited with an exceptional energy trajectory throughout much of its history. Meanwhile, important regional differences in energy regime and economic development long existed within the Low Countries

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[14] Simon Guy and Elizabeth Shove, *A Sociology of Energy, Buildings and the Environment: Constructing Knowledge, Designing Practice* (London-New York: 2000); Mogens Rüdiger (ed.), *The Culture of Energy* (Newcastle: Cambridge Scholars Publishing, 2008); Sarah Strauss, Stephanie Rupp and Thomas Love (eds.), *Cultures of Energy: Power, Practices, Technologies* (Walnut Creek, CA: Left Coast Press, 2013); Harold H. Schobert, *Energy and Society: An Introduction* (London: Routledge, 2014); Smil, *Energy and Civilization*; Imre Szeman and Dominic Boyer (eds.), *Energy Humanities: An Anthology* (Baltimore, MD: Johns Hopkins University Press, 2017); Brent Ryan Bellamy and Jeff Diamanti (eds.), *Materialism and the Critique of Energy* (Chicago, IL: MCM' Publishing, 2018).

[15] Stephen Mosley, *The Chimney of the World: A History of Smoke Pollution in Victorian and Edwardian Manchester* (Cambridge: White Horse Press, 2001).

[16] On a genealogy of the concept, see John Bellamy Foster, *Marx's Ecology: Materialism and Nature* (New York: Monthly Review Press, 2000).

[17] Marina Fischer-Kowalski and Hemut Haberl, *Socio-Ecological Transitions and Global Change: Trajectories of Social Metabolism and Land Use* (Northampton: Edward Elgar, 2007); Fridolin Krausmann, "A city and its hinterland: Vienna's energy metabolism 1800-2006", in *Long Term Socio-Ecological Research: Studies in Society-Nature Interactions across Spatial and Temporal Scales*, edited by Simron Jit Singh et al. (Dordrecht: Springer, 2013), 247-268; Sabine Barles, "Society, energy and materials: what are the contributions of industrial ecology, territorial ecology and urban metabolism to sustainable development?", *Journal of Environmental Planning and Management* 53:4 (2010), 439-455; Dieter Schott, "Energizing European cities: from wood provision to solar panels – providing energy for urban demand, 1800-2000", in *Urbanizing Nature: Actors and Agency (Dis)Connecting Cities and Nature since 1500*, edited by Tim Soens, Dieter Schott, Michael Toyka-Seid and Bert De Munck (London: Routledge, 2020), 135-156.

[18] Jason W. Moore, *Capitalism in the Web of Life: Ecology and the Accumulation of Capital* (London: Verso, 2015).

itself.[19] The Southern Low Countries is often cited as an example of an early 'mineral economy'. After quickly making the transition to coal, it became one of the first regions to industrialise outside the British Isles.[20] The Northern Low Countries, on the other hand, could be viewed as a prototypical case of an 'advanced organic economy'. While the Dutch Republic had profited during its Golden Age from its large deposits of peat, it lacked the crucial transition to coal, causing its economy to stagnate from the early eighteenth century onwards. Although the idea of Dutch industrial retardation still remains largely untouched on a (proto) national level, recent literature has come to emphasise more strongly the geographical variance of development in the 'dual economy' of the Low Countries.[21] In the Southern Low Countries, indeed, the availability of coal was limited to the smaller area of the Walloon axis between Charleroi and Liège, while the city of Ghent was more of an industrial island in the rural region of Flanders. Industrialisation in the Northern Low Countries was generally less rapid, but here as well cities like Leiden and Tilburg were important exceptions to this rule. Did Holland's path dependence on peat present Leiden entrepreneurs with a comparative disadvantage on the international market, preventing them to equally invest in coal-fired mechanisation as their competitors from Ghent? In what ways, in other words, was the industry in the two cities under scrutiny constrained (or not) by the energy basis of their respective economies? By looking at the industrial energy consumption, I will try in what follows below to determine what economic sectors were exactly behind the adoption of coal – both in Ghent and in Leiden, from the seventeenth to nineteenth centuries.

Energy transitions and economic divergence in the Low Countries

The divergent developments within the Low Countries' regional economies have long puzzled historians: why did the Northern Low Countries experience early modern growth, but no industrialisation until the late nineteenth century? And why, by contrast, did the Southern Low Countries turn into the first industrialised region on the Continent after experiencing centuries of relative economic decline? As in the debate on the prime movers of the English *Sonderweg*, access to mineral energy has certainly appeared to historians as a necessary – and perhaps even obvious – condition to explain the Low Countries' conundrum – witness the 'energy debates' on the role of fuel accessibility in the economies of medieval Flanders and

[19] For the general development of the Low Countries' economy, see Bruno Blondé, Marc Boone and Anne-Laure Van Bruaene (eds.), *City and Society in the Low Countries, 1100-1600* (Cambridge: Cambridge University Press, 2018); Jan de Vries and Ad van der Woude, *The First Modern Economy: Success, Failure and Perseverance of the Dutch Economy, 1500-1815* (Cambridge: Cambridge University Press, 1997); Joel Mokyr, *Industrialization in the Low Countries, 1795-1850* (New Haven, CT: Yale University Press, 1976).

[20] Herman Van der Wee, "The industrial revolution in Belgium", in *The Industrial Revolution in National Context: Europe and the USA*, edited by Mikulás Teich and Roy Porter (Cambridge: Cambridge University Press, 1996), 64-77.

[21] Jan Luiten van Zanden, "Industrialization in The Netherlands", in *The Industrial Revolution in National Context: Europe and the USA*, edited by Mikulás Teich and Roy Porter (Cambridge: Cambridge University Press, 1996), 78-94. For the regional variance of the industrial revolution in Europe more generally, see Sydney Pollard, *Peaceful Conquest: The Industrialization of Europe, 1760-1970* (Oxford: Oxford University Press, 1982).

Brabant, Golden-Age Holland, and the eighteenth- and nineteenth-century Southern Low Countries. It was J.W. de Zeeuw who first argued that the Dutch Golden Age was 'born of turf'.[22] Although little of his estimates has survived the test of time, most historians have supported De Zeeuw's initial thesis on the historical importance of energy – at least in combination with other factors of change – in early modern economic development. Wrigley has largely followed De Zeeuw's argument, claiming that Dutch peat crucially expanded the energy resources to enable an 'advanced organic economy' to emerge.[23] Richard W. Unger suggested that De Zeeuw had considerably overestimated the energy supplied by peat while underestimating the importance of the import of coal and the use of wind energy in early modern Holland. Still, Unger maintained that '[m]uch of the industrial growth depended on the use of fossil fuels, principally peat but increasingly coal.'[24]

Meanwhile, historians have also highlighted the role of energy in the Southern Low Countries, in particular in the principalities of Flanders and Brabant. It is well known from the research of Tim Soens and Erik Thoen – and that of others – that peat was the most important source of energy during the urbanisation process and economic boom of medieval Flanders.[25] Preliminary research has also shown that in sixteenth-century Brabant urban growth was mostly fuelled by peat as well. There, the city of Antwerp depended on the import of large quantities of peat to fuel industrial facilities such as the brewing industry as well as to satisfy domestic needs.[26] At the same time, Chris Vandenbroeke pioneered a history of energy for the early modern Southern Netherlands and nineteenth-century Belgium – again, particularly for Flanders.[27] His research has indicated that the nascent energy crisis in Flanders caused by the depletion of wood and peat reserves was eventually overcome in the course of the eighteenth century by the growing use of coal imported from the Walloon deposits in the south of the Austrian Netherlands. The demand for coal as an alternative for peat and wood stimulated the mining sector to grow into a major industry, which had a positive feedback

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[22] De Zeeuw, "Peat and the Dutch Golden Age". See also: P. van Schaik, "De economische betekenis van de turfwinning in Nederland (I). Een historische verkenning", *Economisch- en Sociaal-Historisch Jaarboek* 32 (1969), 141-205; and idem, "De economische betekenis van de turfwinning in Nederland (II). Een historische verkenning", *Economisch- en Sociaal-Historisch Jaarboek* 33 (1971), 186-235; and more recently: Charles Cornelisse, *Energiemarkten en energiehandel in Holland in de late middeleeuwen* (Hilversum: Verloren, 2008).

[23] Wrigley, *Continuity, Chance and Change*, 34 ff.

[24] Richard W. Unger, "Energy sources for the Dutch Golden Age". For the most up-to-date figures on peat consumption and production in the Netherlands, see M.A.W. Gerding, *Vier eeuwen turfwinning: de verveningen in Groningen, Friesland, Drenthe en Overijssel tussen 1550 en 1950* (Wageningen: AAG Bijdragen, 1995); and Jan Luiten van Zanden, "Werd de Gouden Eeuw uit turf geboren? Over het energiegebruik in de Republiek in de zeventiende en achttiende eeuw", *Tijdschrift voor Geschiedenis* 110 (1997), 484-499.

[25] Tim Soens and Erik Thoen, "Mais où sont les tourbières d'antan? Géographie, chronologie et stratégies économiques du tourbage en Flandre maritime (12^{e}-16^{e} siècles)", *Aestuaria: Histoire et Terres Humides* 14 (2009), 45-60; Also: Iason Jongepier et al., "The brown gold: a reappraisal of medieval peat marshes in Northern Flanders (Belgium)", *Water History* 3:2 (2011), 73-93.

[26] Hugo Soly, *Urbanisme en kapitalisme te Antwerpen in de 16de eeuw: de stedebouwkundige en industriële ondernemingen van Gilbert van Schoonbeke* (Brussels: Gemeentekrediet van België, 1977); Floris Prim, *Geschiedenis van het Antwerpsche turfdragersambacht (1447-1863)* (Antwerp: Veritars, 1923).

[27] Vandenbroeke, "De problematiek van de energievoorziening"; idem, "Zuinig stoken".

loop on other industries as well when coal became the principal energy source to power the cotton, woollen and iron industries in the early industrial nation of Belgium.[28]

When zooming in on the historical composition of the energy mix in the two cities at hand, the general differences between the North and the South are reconfirmed.[29] While Ghent experienced a radical shift towards coal from the middle of the eighteenth century onwards, the energy regime in Leiden remained predominantly based on the energy derived from peat until far into the nineteenth century. Before the rise of coal the dominant fuel in Ghent was firewood, which accounted for roughly 40 to 50 per cent of the total energy consumed. In total, fuelwood (both firewood and charcoal) accounted for about half of the energy used in 1700. It is remarkable that coal – mostly from the Borinage area which reached Ghent via the Scheldt river – in the middle of the seventeenth century already delivered approximately 15 to 20 per cent of the energy required – a percentage that would remain stable until the middle of the century. Besides firewood, food for eating was the other major source of energy for the pre-industrial regime, reaching about 33 per cent before 1800. The combined role of fodder and wind and water energy remained marginal during the entire period (under 2 per cent). By all accounts, coal would eventually supersede the entirety of the Ghent energy mix. Even though coal was already available to consumers and (artisanal) industries and its consumption had already reached quite significant but not growing levels by the beginning of the seventeenth century, it was only after 1750 that a true 'energy revolution' occurred in that city. By the end of the study period, coal would account for nearly 95 per cent of the total energy consumption in Ghent; the Flemish city had reached its 'peak coal'.

The Leiden economy followed a more fuel-intensive path of energy consumption as early as during the seventeenth and eighteenth centuries. Food and feed – and thus human and animal labour – played a minor role in comparison to those in Ghent – reaching 16 per cent at the start of the study period, which was more or less half of the level in Ghent. Fuels (both fossil and renewable) accounted for 81 per cent in 1700, while their combined share in Ghent reached only 66 per cent of the urban total. The role of fuelwood in Leiden was much smaller than in Ghent, since it supplied only around 5 to 10 per cent of the energy used. Wind and water played a similar – i.e. marginal – role. In the seventeenth century, Leiden had already achieved the status of an advanced energy economy – albeit still largely powered by peat instead of coal. The city was a typical example of Holland's 'proto-fossil' trajectory in which peat to a great extent supplemented soil-dependent energy sources such as wood and food. In the middle of the seventeenth century, during Holland's phase of 'peak peat', the

[28] Hervé Hasquin, *Une mutation: le pays de Charleroi aux 17e et 18e siècles: aux origins de la revolution industrielle en Belgique* (Brussels: Éditions de l'Institut de Sociologie, 1971); Cécile Douxchamps-Lefevre, "Le commerce du charbon dans les Pays-Bas autrichiens à la fin du XVIIIe siècle", *Revue Belge de Philologie et d'Histoire* 46:2 (1968), 393-421; Jan Dhondt and Marinette Bruwier, "The Industrial Revolution in the Low Countries 1700-1914", in *The Fontana Economic History of Europe. Volume IV: 1700-1914. Part One: The Emergence of Industrial Societies*, edited by Carlo M. Cipolla (Hassocks: Harvester Press, 1976), 329-366.

[29] The figures on the energy regime of Ghent and Leiden in the seventeenth to nineteenth centuries will be published elsewhere: Wouter Ryckbosch and Wout Saelens, "Fuelling the urban economy: a comparative study of energy in the Low Countries, 1600-1850", *The Economic History Review* (forthcoming).

brown fuel supplied about three quarters of the energy in Leiden's 'urban metabolism'. Coal, on the other hand, would never reach a substantial level during the period studied. Though coal consumption surely was not entirely absent in early modern Holland, it hardly ever exceeded a level of 10 per cent of the total energy mix and achieved a maximum of 15 per cent in the middle of the nineteenth century. Even when the role of peat began to decrease after 1750, this was mostly compensated for by a higher consumption of firewood. Only after 1815 did the consumption of coal begin to experience some initial growth in Leiden, when the unification of the Northern and Southern Netherlands improved the integration of Walloon coal into one national market.[30] By the time of Belgian independence in 1830, however, the access of the Dutch to coal from the South was blocked off once again. As Ben Gales has demonstrated, the coal age in the Dutch Low Countries was very much a phenomenon of the late nineteenth and early twentieth centuries. Only around 1900 did coal become the dominant energy supplier in the Netherlands.[31]

Soon to become the 'Manchester of the Continent', the blessing of coal arrived to Ghent precisely at a time of large-scale economic expansion. After having been a major producer of woven cloth in the later Middle Ages and after experiencing a period of postmedieval decline,[32] the expansion of industrial production of linen and cotton textiles in the eighteenth and nineteenth centuries turned Ghent into one of the first industrialising cities on the European mainland.[33] The output of (mechanised) cotton production especially increased at an astonishing rate. In 1810, the spinneries and printing factories accounted for an annual production of more than 100,000 pieces. By 1826, more than 400,000 pieces of cotton were produced annually.[34] The number of textile workers involved increased as well: from 1,400 in 1794 to 5,000 in 1807 and 11,600 in 1830.[35] The rapid growth in Ghent stood in sheer contrast to the prolonged decline experienced in Leiden. As in medieval Ghent, Leiden's most important economic activity was the production of woollen textiles for export. Its textile industry flourished during the seventeenth century, when Leiden became one of the most prominent textile centres in the whole of Europe characterised by an early factory-like organisation with manufacturers ('*fabrikanten*') employing several wage labourers.[36] During the eighteenth

[30] Jan Luiten van Zanden and Arthur van Riel, *The Strictures of Inheritance: The Dutch Economy in the Nineteenth Century* (Princeton: Princeton University Press, 2004), 206-210.

[31] Gales et al., "North versus South", 224; Ben Gales, *Delven en slepen: steenkolenmijnbouw in Limburg: techniek, winning en markt gedurende de achttiende en negentiende eeuw* (Hilversum: Verloren, 2004).

[32] Marc Boone, "L'industrie textile à Gand au bas moyen âge ou les resurrections successives d'une activité réputée moribonde", in *La draperie ancienne des Pays-Bas. Débouchés et stratégies de survie, 14e-16e siècles*, edited by Marc Boone and Walter Prevenier (Leuven: Garant, 1993), 122-135.

[33] J. Hannes, "Industrialization without development. Some aspects of the history of Ghent", in *Regional Capitals: Past, Present, Prospects. Ghent, Groningen, Münster, Norwich, Odense, Rennes*, edited by Pim Kooij and Pieter H. Pellenbarg (Assen: Van Gorcum, 1994), 9-18.

[34] Hilda Coppejans-Desmedt, *De Gentse textielnijverheid van 1795 tot 1835: het proces van mechanisering in zijn economische gevolgen* (unpublished PhD thesis: University of Gent, 1958), 473-483, 508.

[35] Jan Dhondt, "Notes sur les ouvriers industriels gantois à l'époque française", *Revue du Nord* 36 (1954), 309-324; Peter Scholliers, *Wages, Manufacturers and Workers in the 19th Century Factory: The Voortman Cotton Mill in Gent* (Oxford: Berg, 1996), 219.

[36] N.W. Posthumus, *De geschiedenis van de Leidsche lakenindustrie* (The Hague: Martinus Nijhoff, 1939).

century, however, the city's industries did nothing but decline. Sure enough, Leiden remained the most important textile city in the Netherlands, together with Haarlem and Tilburg, until at least the first half of the nineteenth century.[37] Despite its relative economic resilience in the production of woollen cloth, Leiden never became an industrialised centre like its counterpart in Flanders. By the end of the seventeenth century, the Leiden cloth industry had reached its peak, after which a steady decline followed. In 1671, textile production peaked at 139,000 pieces per year, while by 1800 its output had dropped to fewer than 30,000 pieces.[38] The figures available for the nineteenth century are underestimations, but the overall trend does not show any sign of recovery after the turn of the century.[39] Correspondingly, the number of people working in the textile industry decreased along the way; it employed about 3,200 workers in 1749, 2,715 in 1808, and 1,000 in 1849 – though a class of manufacturers always remained active in the city.[40]

Until the middle of the eighteenth century the population size of the two cities had been very similar – ranging between 40,000 and 50,000 inhabitants. After that, the number of citizens in Ghent climbed from c. 45,000 in 1750 to 55,000 in 1800 and to more than 100,000 in 1850.[41] After a period of relative demographic stability, the population of Leiden experienced a steady decline from the last quarter of the seventeenth century until the second quarter of the nineteenth. Around 1825, its demography had reached an all-time low, when there were c. 30,000 inhabitants within the city walls.[42] Only from the 1830s onwards did the population of Leiden experience a modest rise, but it would never again catch up with Ghent. At the beginning of the study period, both the economic and demographic circumstances of the two cities were highly comparable. By the middle of the nineteenth century, however, they had diverged considerably. Over the course of the eighteenth and nineteenth centuries, the Malthusian advantages in the Low Countries – in terms of fuel acreage – seem to have shifted from the North to the South.

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[37] Michael Jansen, *De industriële ontwikkeling in Nederland 1800-1850* (Amsterdam: NEHA, 1999).

[38] Posthumus, *De Geschiedenis van de Leidsche lakenindustrie*, II, 930-931, 1098-1099.

[39] G.A. Reimeringer, "De ontwikkeling der Leidsche textielnijverheid in de 19de eeuw", *Leidsch Jaarboekje* 14 (1917), 129-145.

[40] H.A. Diederiks, "Beroepsstructuur en sociale stratificatie in Leiden in het midden van de achttiende eeuw", in *Armoede en sociale spanning: sociaal-historische studies over Leiden in de achttiende eeuw*, edited by H.A. Diederiks, D.J. Noordam and H.D. Tjalsma (Hilversum: Verloren, 1985), 45-68; H.D. Tjalsma, "Leidse textielarbeiders in de achttiende eeuw", in *Stof uit het Leidse verleden: zeven eeuwen textielnijverheid*, edited by J.KS. Moes and B.M.A. de Vries (Utrecht: Matrijs, 1991), 91-100.

[41] Hans Van Werveke, *De curve van het Gentse bevolkingscijfer in de 17e en de 18e eeuw* (Brussels, 1948); Paul Deprez, "Het Gentse bevolkingscijfer in de tweede helft van de achttiende eeuw", *Handelingen der Maatschappij voor Geschiedenis en Oudheidkunde te Gent* XI (1957), 177-195; Oscar Bergmans, *Mouvement de l'état-civil et de la population de la ville de Gand au 19e siècle et notice sur les registres anciens et modernes conservés à l'état-civil de Gand* (Ghent: Meyer-Van Loo, 1902).

[42] Dirk Jaap Noordam, "Demografische ontwikkelingen", in *Leiden: de geschiedenis van een Hollandse stad. Deel2: 1574-1795*, edited by R.C.J. van Maanen (Leiden: Stichting Geschiedschrijving, 2004), 43-53; H.D. Tjalsma, "De bevolking", in *Leiden: de geschiedenis van een Hollandse stad. Deel 3: 1795-1896*, edited by R.C.J. van Maanen (Leiden: Stichting Geschiedschrijving, 2004), 41-51.

Fuel-intensive industry in Ghent and Leiden

How did the energy divergences in the Low Countries affect the industrial development in each city under scrutiny? The historical relationship between energy and industrialisation was of course a technological relationship. As 'conceptually one of the most radical inventions ever made', the steam engine in particular has made this relationship between energy and the industrial revolution into an intimate one.[43] Although indeed the invention of the steam engine would allow advanced organic economies finally to break through their natural constraints and turn into proper mineral economies, early coal (or peat) economies could already benefit from the new energy opportunities that fossil fuels provided before large-scale industrialisation kicked in. According to De Zeeuw, peat explained the success of many heat-intensive industries in the Dutch Golden Age: brewing, brick manufacture, lime burning, salt and sugar refining, soap production, distilling, bleaching and dyeing of textiles, pottery making, and so on; as the cheap energy allowed these crafts to run on 'thermal processes'.[44] Similar observations have been made for England where most of these industries had completed the switch to coal by the end of the seventeenth century.[45] According to Wrigley, the transition to coal – before it became a source of motion – 'made it possible to prolong the benefits flowing from a "Smithian" economy in which the "hidden hand" helped to ensure that capital was used profitably and economically'.[46]

Adopting a methodology similar to that of William M. Cavert, who studied industrial coal consumption in early modern London, I have tried to estimate the amount of fuel energy (excluding food, fodder, wind and water energy) consumed by the most important heat-intensive crafts in Ghent and Leiden over the course of the seventeenth to nineteenth century.[47] Assuming that each unit of production required a determined amount of energy, production estimates were used to reconstruct the fuel needs of the industries mentioned above – mostly on the basis of taxes levied on production or on the consumption[48] of their products (see the methodological appendix below for a listing of the details behind these calculations). The industrial activities considered here are textile bleaching and dyeing, brewing, bread baking, distilling, salt and sugar refining, brick and lime making, soap making, glass making, pottery making, and steam-powered textile production. These were of course not the only crafts around that required energy (consider for instance the work of a blacksmith) but they certainly were the largest industrial consumers in both towns under scrutiny. Therefore, the

[43] Joel Mokyr, "Introduction: the new economic history and the industrial revolution", in *The British Industrial Revolution: An Economic Perspective*, edited by Joel Mokyr (Boulder: Westview Press, 1993), 19-20.
[44] De Zeeuw, "Peat and the Dutch Golden Age", 23.
[45] John Hatcher, *The history of the British coal industry. Volume 1: before 1700: towards the age of coal* (Oxford: Clarendon Press, 1993), 458.
[46] Wrigley, *Energy and the Industrial Revolution*, 41.
[47] William M. Cavert, "Industrial coal consumption in early modern London", *Urban History* 44:3 (2017), 424-443.
[48] The data on brewing (Ghent), baking, distilling, salt refining and soap boiling in fact relate to consumption volumes rather than production figures. 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.

calculations given in tables 1 and 2 account for a minimal amount of industrial fuel consumption in Ghent and Leiden.

Table 1. Fuel consumption by industry in Ghent, 1650-1850 (in GJ).

	1650	**1700**	**1750**	**1800**	**1850**
Bleaching and dyeing	67,500	91,859	94,938	103,689	28,944
Brewing	14,555	29,613	16,866	23,720	37,529
Baking	1,375	1,540	1,188	1,589	2,548
Distilling	(3,105)	3,119	2,496	7,932	7,636
Salt	(36,765)	36,749	19,713	12,154	(23,205)
Sugar	0	0	6,443	83,759	83,759
Brick and lime	17,333	19,733	10,484	9,748	(18,585)
Soap	(4,683)	4,683	6,160	3,523	(6,726)
Glass	(21,788)	21,659	14,615	0	0
Pottery	2,873	(2,134)	1,890	378	(722)
Steam	0	0	0	8,910	1,416,690
Sum	169,977	211,088	174,793	255,402	1,626,344
Total fuel energy	706,362	834,051	563,115	1,655,817	6,325,881
% industrial	**24**	**25**	**31**	**15**	**26**
% rest	**76**	**75**	**69**	**85**	**74**
Ghent population	45,000	45,000	39,000	55,000	105,000
Energy per capita	16	19	14	30	60

Note: figures between brackets were extrapolated.

Sources: see methodological appendix.

Table 2. Fuel consumption by industry in Leiden, 1650-1850 (in GJ).

	1650	**1700**	**1750**	**1800**	**1850**
Bleaching and dyeing	249,761	229,514	145,657	79,472	16,097
Brewing	71,936	41,106	41,106	(3,184)	(3,744)
Baking	4,587	2,806	2,746	2,213	(2,612)
Distilling	(6,612)	(7,152)	4,993	3,669	2,123
Brick and lime	16,538	20,318	(7,653)	6,332	(7,447)
Soap	22,377	22,691	21,754	23,290	(27,490)
Glass	30,375	30,375	28,350	28,350	(33,462)
Pottery	1,890	(2,044)	(1,427)	(1,181)	(1,389)
Steam	0	0	0	0	187,110
Sum	404,074	356,005	253,686	147,690	281,475
Total fuel energy	2,189,636	1,536,650	1,188,517	925,953	1,895,072
% industrial	**18**	**23**	**21**	**16**	**15**
% rest	**82**	**77**	**79**	**84**	**85**
Leiden population	49,000	53,000	37,000	30,500	36,000
Rest energy per capita	36	22	25	26	45

Note: figures between brackets were extrapolated.

Sources: see methodological appendix.

Before the introduction of steam engines, many industries in Leiden and Ghent already required large quantities of fuel. Around 1650, the total energy consumed annually by industry was 169,977 GJ in Ghent and 404,074 GJ in Leiden – which would correspond with about 14,000 and 32,000 metric tons of firewood, respectively. These numbers remained rather stable and were slightly higher in Leiden than in Ghent up until the beginning of the nineteenth century. Total per capita fuel energy levels (both industrial and domestic) fluctuated between 14 and 30 GJ in Ghent and between 29 and 45 GJ in Leiden – suggesting that peat in the early modern period indeed allowed more heat-intensive industry to develop in Holland.

In both cities, the textile bleaching and dyeing sectors were the most important industrial energy consumers of the pre-steam age. In Ghent, bleaching and dyeing were responsible for about 40 to 54 per cent of all the industrial energy consumption (table 3). In Leiden, these accounted for 62 to 54 per cent of the total energy consumption by industry before 1850 (table 4). Although bleaching and dyeing activity used a smaller proportion of energy in terms of the relative cost of fuel within their total costs when compared to other sectors, these textile finishing industries were so huge that the combined amount of fuel consumed in them easily exceeded that of any other industry, definitely in the two cities discussed here. Bleachers and dyers needed fuel to heat the vats in which wool, linen, cotton or silk textiles were scoured. In the early modern period, Leiden was a famous producer of high-quality dyed cloths,[49] whereas Ghent in the seventeenth and eighteenth centuries became an important centre for the bleaching of linen textiles that were produced in the surrounding countryside in a proto-industrial system.[50]

Table 3. Relative share of fuel consumption by industry in Ghent, 1650-1850 (in %).

	1650	**1700**	**1750**	**1800**	**1850**
Bleaching and dyeing	40	44	54	41	2
Brewing	9	14	10	9	2
Baking	1	1	1	1	0
Distilling	2	1	1	3	0
Salt	22	17	11	5	1
Sugar	0	0	4	33	5
Brick and lime	10	9	6	4	1
Soap	3	2	4	1	0
Glass	13	10	8	0	0
Pottery	2	1	1	0	0
Steam	0	0	0	3	87
Total	100	100	100	100	100

Sources: see methodological appendix.

[49] Posthumus, *De geschiedenis van de Leidsche lakenindustrie*.

[50] Etienne Sabbe, *De Belgische vlasnijverheid* (Kortrijk: Nationaal Vlasmuseum, 1975); Joseph Bastin, "De Gentse lijnwaadmarkt en linnenhandel in de XVIIe eeuw", *Handelingen der Maatschappij voor Geschiedenis en Oudheidkunde te Gent* (21 (1967), 131-162.

Table 4. Relative share of fuel consumption by industry in Leiden, 1650-1850 (in %).

	1650	1700	1750	1800	1850
Bleaching and dyeing	62	64	57	54	6
Brewing	18	12	16	2	1
Baking	1	1	1	1	1
Distilling	2	2	2	2	1
Brick and lime	4	6	3	4	3
Soap	6	6	9	16	10
Glass	8	9	11	19	12
Pottery	0	1	1	1	0
Steam	0	0	0	0	66
Total	100	100	100	100	100

Sources: see methodological appendix.

Other important fuel-consuming industries were of course bread baking and beer brewing (up to 19 per cent in Leiden and 15 per cent in Ghent). 'Bakers and brewers had their fixed place in urban society; they produced staples and therefore had a rightful claim to firewood', as Joachim Radkau has noted.[51] Similarly, in his case study of Parisian bakers in the eighteenth century, Steven L. Kaplan found that 'wood and wheat were inseparably linked'.[52] Because of their importance in feeding the city, the guilds of bakers and brewers had gained a lot of political power since the late Middle Ages already. And on the basis of that power they tried to impose on the city government their concerns about sufficient fuel provisioning. Intermittently, bakers and brewers from various cities in the Low Countries would complain that the cost of fuel was too high for them to deliver products at a reasonable price that still afforded a reasonable profit.[53]

Glass makers consumed a fair share of fuel as well. A guild of glass makers existed in Leiden from 1618 until 1812.[54] In Ghent, the glass industry developed quickly in the seventeenth century, but had already disappeared before the close of the eighteenth century, as a result of growing competition from the French market that better responded to shifting consumer demands towards more luxurious articles.[55] Glass makers in both towns mostly produced simple bottles, but occasionally also fabricated window glasses and mirrors. It was a capital-intensive sector, with high costs for raw materials, fuels and infrastructure. In the middle of the seventeenth century fuel consumption for glass making still accounted for about 13

[51] Joachim Radkau, *Wood: A History* (Cambridge: Polity Press, 2012), 94-95.

[52] Steven L. Kaplan, *The Bakers of Paris and the Bread Question, 1700-1775* (Durham: Duke University Press, 1996), 76.

[53] Hugo Soly, "De economische betekenis van de zuidnederlandse brouwindustrie in de 16e eeuw. Problematiek", *Studia Historica Gandensia* 179 (1973), 97-117; Stefanie Gilté, *Het Brugse bakkersambacht in de nieuwe tijden* (unpublished MA thesis, University of Ghent, 1996); Richard W. Unger, *A History of Brewing in Holland, 900-1900: Economy, Technology and the State* (Leiden: Brill, 2001); Karel Davids, *The Rise and Decline of Dutch Technological Leadership: Technology, Economy, and Culture in the Netherlands, 1350-1800* (Leiden: Brill, 2008), 143, 468-469.

[54] City Archives Leiden (hereafter: GAL), Gilden, namen van meesters, leerlingen enz. 1574-1812.

[55] Paul Van Heesvelde, "De glasnijverheid te Gent, 1693 – ca. 1730", *De Oost-Oudburg* 27 (1990), 75-76.

per cent in Ghent, gradually decreasing after that. In Leiden, glass makers consumed about 8 per cent around 1650 and 19 per cent around 1800 of all the industrial fuel consumption.

Two other sectors that were important consumers of energy were salt refining and soap boiling. In the first half of the seventeenth century the first salt refineries appeared in Ghent, when the construction of a canal to Ostend provided the city with better access to the sea.[56] The extraction of salt had long been concentrated in the coastal area where sea water was naturally evaporated by exposing it to the sun. In Ghent, however, the access to coal allowed salt refiners to extract salt from brine in artificially created open pans which were placed above a stokehold – using c. 22 per cent of the industrial energy consumption around 1650. Salt refiners produced crude salt as well as washing soda or *sel-de-soude*. Companies therefore often specialised in the refining of both salt and soda. Although Holland was known to have produced substantial amounts of salt – mostly directed at the needs of the herring sector – no such trade was found in Leiden, even though the city, like Ghent, seems to have produced soap.[57] Similarly, sugar refinery started to develop in Ghent from the middle of the eighteenth-century onward, but it did not in Leiden. In the former city, sugar refining eventually even became the biggest industrial fuel consumer by the turn of the nineteenth century. In 1804 the French prefect Guillaume Faipoult counted in his *Mémoire statistique du Département de l'Escaut* thirteen sugar refineries in Ghent which collectively accounted for 33 per cent of all industrial fuel consumption.[58] Sugar cane was imported from the New World and reached Ghent via the Coupure canal which was constructed in 1751,[59] enabling the sugar industry to grow exponentially and to meet the ever growing demand for sweetness of the eighteenth-century consumer.[60] Finally, in a pre-industrial context, fuel energy was also crucial for some niche industries such as distilling, brick and lime making, and pottery production.

Despite the importance of (fossil) fuel for industrial production before the industrial revolution, the introduction of steam power around the turn of the nineteenth century would more than anything else change the relationship between energy and industry. Only when the steam engine allowed for the conversion of the heat energy contained in fossil fuels into mechanical energy could a growing number of manufacturing sectors follow an energy-intensive (and labour-saving) path of growth. This pursuit for energy as a source of motion was mostly felt in the production of textiles, particularly so in the cotton industry – 'the wonder industry of the Industrial Revolution.'[61] The first steam engines found their way to the Ghent

[56] Guido Deseijn, "Zoutproductie in Gent, eerste en oudste geïndustrialiseerde stad van Vlaanderen (1750-1900)", *Tijdschrift voor Industriële Cultuur* 67:3 (1999), 19.
[57] De Vries and Van der Woude, *The First Modern Economy*, 419-420.
[58] Guillaume Faipoult, *Mémoire statistique du Département de l'Escaut*, edited by Paul Deprez (Ghent: Maatschappij voor Geschiedenis en Oudheidkunde, 1960 [orig. 1804]), 175.
[59] Guido Deseijn, *Bouwen voor de industrie: een verkenning in het Manchester van het vasteland* (Ghent: MIAT, 1989), 224.
[60] Sidney W. Mintz, *Sweetness and Power: The Place of Sugar in Modern History* (New York: Viking, 1985).
[61] Allen, *The British Industrial Revolution*, 182.

textile industry in the closing years of the eighteenth century.[62] From the 1780s onwards cotton printing became the largest industry in Ghent, and soon employed thousands of labourers. In cotton spinning perpetuals and jennies had been in use before 1795 already,[63] but mechanisation on a larger scale began when the industrialist Lieven Bauwens smuggled a spinning mule and Newcomen engine from Manchester to Ghent in 1797.[64] By 1810 there were four steam engines in the Ghent industries, rising to 27 by 1820, 66 by 1830 and over a hundred before the middle of the nineteenth century.[65] By then, steam-powered factories accounted for a 87 per cent share of all the fuel consumed by industry. The early mechanisation of the textile industry in Ghent stood in contrast to the situation in Leiden, where industrial mechanisation not only happened in a later stage but where it also was much less profound. In Leiden, the first steam engine was introduced in wool spinning in 1816. By 1830 there were only 4 steam engines in the city – a figure that did not rise above 21 until the second half of the nineteenth century.[66]

The rise of steam was followed by a significant increase of the absolute amount of the estimated total of industrial energy consumption – in Ghent, but also – albeit to a lesser extent – in Leiden. In the latter city, the sum of industrial energy consumption recovered by the middle of the nineteenth century towards a level of 281,475 GJ. Though this level could in absolute terms hardly match the level of the mid-seventeenth century, it still accounted for a renewed increase after a long period of decline mostly driven by steam-powered manufacturing – reaching a 66 per cent relative share of the industrial energy consumption. This was definitely true when viewed in relation to population changes, as the per capita energy consumption (including both industrial and domestic fuel uses) in Leiden rose to 53 GJ. In Ghent, the industrial energy consumption grew spectacularly in the first half of the nineteenth century, reaching a level of 1,626,344 GJ around 1850. In per capita terms, the total energy consumption had risen to 60 GJ in Ghent and 53 GJ in Leiden at the end of the period studied. Despite the differences between the two, it is clear that both Ghent and Leiden required a growing 'metabolic' flow of energy to sustain urban activity.

Coal-burning trajectories

At first glance, the central research hypothesis of this paper seems confirmed. Initially, peat had favoured the growth of heat-intensive industries in the early modern period, but

[62] Anne Van Neck, *Les débuts de la machine à vapeur dans l'industrie belge: 1800-1850* (Brussels: Académie Royale de Belgique, 1979), 77 ff. and 101 ff.
[63] Coppejans-Desmedt, "De Gentse textielnijverheid", 151-2.
[64] Jan Dhondt, "L'industrie cotonnière gantoise à l'époque française", in *Hommes et pouvoirs: les principales études de Jan Dhondt sur l'histoire du 19e et du 20e siècles* (Ghent: Fondation Jan Dhondt, 1976), 208-267; Hilda Coppejans-Desmedt, "De betekenis van Gent voor de expansie van de katoennijverheid in de Nederlanden", *Textielhistorische Bijdragen* 11 (1969), 17-27.
[65] Van Neck, *Les débuts*, 824-7.
[66] C.B.A. Smit, "De introductie van de stoomkracht in Leiden", in *Uit Leidse bron geleverd*, edited by J.W. Marsilje (Leiden: Gemeentearchief Leiden, 1989), 529.

eventually prevented industrial mechanisation in the eighteenth and nineteenth centuries. In the Southern Low Countries, on the other hand, the transition to coal around 1750 was quickly followed by the second-phase transition of industrialisation in which coal became a source of labour-saving machine technology. While peat, in other words, had allowed some pre-industrial 'Smithian' growth, it was only through coal that such growth could be translated into modern 'Schumpeterian' growth based on technological innovation.

At closer inspection, however, such an energy-deterministic reading of the industrial revolution deserves nuance. While it is certainly true that coal mattered in determining the timing and character of the industrial revolution, the relationship between heavy coal consumption and heavy industrial production should not be overstated. In fact, when looking at the relative share of industrial fuel consumers within the city's total energy usage, it is clear that urban industries took up barely one quarter of all the available energy. Most energy was actually consumed by households for cooking, heating and lighting.[67] Even by the middle of the nineteenth century, when steam engines had drastically increased industrial energy consumption across several sectors, a maximal estimation of 74 per cent in Ghent and 85 per cent in Leiden of the fuel consumption was domestic (tables 1 and 2). These findings correspond well with Cavert's research illustrating how in early modern London about 80 to 90 of the coal consumption was by the household rather than industrial economy.[68] This gives additional empirical support to earlier observations by John Hatcher and Robert Allen that Britain's early embrace of coal must have depended on how households 'learned to heat a house with coal'.[69] Both the early transition to coal in Ghent and the continued attachment to peat in Leiden could have been made possible only by the decisions of homemakers to bring new or old fuels into their homes. Only when coal or peat became (or remained) a more attractive fuel for private consumers – in other words, when their relative prices dropped – could new types of energy be widely adopted and the transformation from one energy economy to another be completed. This shows, then, that most energy in Ghent and Leiden during the long eighteenth century was not used to power the industry but rather served the comfort of urban consumers.[70]

While industrial demand for fossil fuel played a rather marginal role in the Low Countries' energy transition throughout the entire period studied, this does not mean that coal was not important for industrial uses before an overall switch to the black fuel was made. As households mostly followed the dynamics of energy prices on the market, it can be assumed that most of this earlier coal consumption was indeed directed at specific industrial needs. In the traditional textile sector, bleachers and dyers long refused to use coal because they feared that dirtying the air with soot would stain their products and hence compromise the quality of the textiles. In Ghent, the linen bleachers are known to have begun using coal from the

[67] The relationship between energy transitions and the daily practices of domestic life is worked out in Wout Saelens, *The Comforts of Energy? Consumer Culture and Energy Transition in Eighteenth-Century Gent and Leiden (1650-1850)* (unpublished PhD thesis, University of Antwerp and Vrije Universiteit Brussel, 2021).
[68] Cavert, "Industrial coal consumption".
[69] Hatcher, *The History of the British Coal Industry*, 409 ff.; Allen, *The British Industrial Revolution*, 90 ff.
[70] Saelens, *The Comforts of Energy*.

second half of the eighteenth century on, when wood prices started to rise. But even then, the use of coal for bleaching remained a trade-off between the financial benefit of cheap energy and the danger of pollution.[71] In 1759 and 1761, the city magistrate still tried to prohibit the consumption of coal entirely after several complaints of bleachers – two attempts that, needless to say, were of no avail.[72] Even as late as 1781, when coal had become the cheapest fuel available, the probate inventory of Catharine Hauwins, wife of the late textile bleacher Joachim de Beer from Ghent, only mentioned firewood as stored in the bleach house.[73] In Leiden, peat was the obvious choice for dyers: it was cheaper and burned much cleaner than coal. Their reliance on peat is evident from a petition from 1778, when the guild of dyers complained to the urban government about the high tax on peat, arguing that it compromised the profitability of their trade.[74] Likewise, bakers did not use coal in their ovens. Since the baking process involved the product being directly in contact with the flames and smoke, they usually preferred as their fuel of choice charcoal, which produced high temperatures but came without the foul smoke of fossil energy.[75]

Other industrial sectors had much closer ties to the coal trade. From their very beginning, the salt and soda industries have always been highly depended on the import of coal which provided the high temperatures required to boil brine over large heated pans.[76] It is because of this large-scale consumption of coal that in 1753 for instance a request for a new soap and salt refinery was rejected by the urban government in Ghent, arguing that the 'green, plentiful smoke or fume, mixed with the excessive and heavy soot' would form too great a danger for the environment.[77] For similar reasons as those of the salt refining and soap boiling, sugar refining depended strongly on the intensive energy of coal fuel.[78] Coal produced very high temperatures that could simply not be achieved by burning wood or peat.

By the seventeenth and eighteenth centuries, most brewers in the Low Countries – both in the South and in the North – had switched to coal as well.[79] John Nef held that in England brewing must have been one of the principal motors behind the coal industry before the industrial revolution.[80] Similar assertions could be made for the Southern Low Countries.[81] As early as the sixteenth century, brewers – and distillers for that matter – in Flanders and Brabant, after chiefly having used peat, gradually shifted to coal. In sixteenth-century Antwerp, for instance, large brewing enterprises such as those of the entrepreneur Gilbert van

[71] Sabbe, *De Belgische vlasnijverheid*, II, 50-54.
[72] Christophe Verbruggen, *De stank bederft onze eetwaren: de reacties op industriële milieuhinder in het 19de-eeuwse Gent* (Ghent: Academia Press, 2002), 19-20.
[73] City Archives Ghent (hereafter: SAG), Series 332, Minuten van staten van goederen, no. 776/13.
[74] N.W. Posthumus, *Bronnen tot de geschiedenis van de Leidsche textielnijverheid, 1333-1795* (The Hague: Martinus Nijhoff, 1910-1922), VI, 668-671.
[75] Nef, *The Rise of the British Coal Industry*, 215-216.
[76] Deseijn, "Zoutproductie in Gent", 20-22.
[77] Idem, *Bouwen voor de industrie*, 227.
[78] Robert Louis Stein, *The French Sugar Business in the Eighteenth Century* (Baton Rouge, LA: Louisiana State University Press, 1988), 132.
[79] Soly, "De economische betekenis", 109; Unger, *A History of Brewing in Holland*, 100-103.
[80] Nef, *The Rise of the British Coal Industry*, 213.
[81] And have been made in Soly, "De economische betekenis" for instance.

Schoonbeke actively invested in the extraction of peat and coal, by acquiring shares in the mining industry or starting a mining company themselves.[82] By the beginning of the seventeenth century, the shift to coal among brewers in the Southern Low Countries was complete.[83] Also in early modern Holland brewers were notable coal consumers. More than any other industry, Dutch brewers petitioned for the permission to use coal. In the first decades of the seventeenth century, brewers in Delft, Dordrecht, Rotterdam and Haarlem asked for authorisation to stoke coal as an alternative to peat in the winter when frozen canals often kept sufficient peat supplies from reaching the towns.[84] After some initial hesitation – brewers were expected to use peat by the government – almost all cities in Holland accepted over the course of the seventeenth century the fuel concerns of the brewing industry and eventually granted it with concessions that allowed brewers to use coal at any time of the year – making coal into a common fuel in Holland breweries (and distilleries) by the end of the seventeenth century.[85]

Glass making was another industry that ranked among the trades that consumed the largest quantities of coal. In the Low Countries, the use of coal in glass making had to do with a change in production. Both in the North and South, the glass making industry started to concentrate on lower segments of the market by mainly producing bottles in the eighteenth century.[86] The technique for bottle making was based on English technology which involved the use of coal-customised furnaces.[87] Coal, in this case, not only had the advantage of generating more heat than wood or peat, which was better suited for the more continuous production of cheap glasswork, but it also had the desired effect of darkening the glass of the bottles.[88] Contrary to the production of more luxurious glassware such as window glass, mirrors and crystal tableware, bottle makers did not have to worry about the smoke of coal potentially contaminating their products. The specialisation in bottle making in the Low Countries' glassworks – 'to English fashion' – thus involved a broader shift to a new production technique.[89] And this tendency towards mass-produced glass based on coal-fired furnaces was as strong in the Northern Low Countries as it was in the South.

From the turn of the nineteenth century onwards steam engines were employed in a rapidly widening range of industrial uses to provide power, but in Leiden and Ghent their earliest histories have to be traced back especially to the spinning, printing and weaving of textiles – although the application of steam in other sectors such as oil milling, paper

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[82] Jean Lejeune, *La formation du capitalisme moderne dans la principauté de Liège au XVIe siècle* (Liège: Faculté de philosophie et lettres, 1939), 343-345.

[83] Marie-Jeanne Eykens, *De brouwindustrie te Antwerpen 1585-1700* (unpublished MA thesis, University of Ghent, 1972).

[84] Unger, *A History of Brewing in Holland*, 101.

[85] Ibidem, 101-102.

[86] Van Heesvelde, "De glasnijverheid te Gent"; P.W. Klein, "Nederlandse glasmakerijen in de zeventiende en achttiende eeuw", *Economisch- en Sociaal-Historisch Jaarboek* 44 (1982), 31-43.

[87] Eleanor S. Godfrey, *The Development of English Glassmaking, 1560-1640* (Chapel Hill: Clarendon Press, 1975).

[88] Darkened glass offered bottled beer and wine a better protection from sunlight: J.A. Kerssies, "Het geheim van de Engelse glasoven. Brandstoftechnologie in de zeventiende-eeuwse glasnijverheid", *Jaarboek voor de Geschiedenis van Bedrijf en Techniek* 4 (1987), 69-84.

[89] Davids, *The Rise and Decline*, 163.

production and metalworking were not uncommon.[90] Like the glass oven, the steam engine was an English invention that was specifically designed to be burned with coal. For this reason, modern machine technology entered the Dutch economy only slowly – as we have already seen above.[91] Moreover, for their mechanical energy, the Dutch have traditionally – and famously so – relied on windmills, as well as watermills and horse mills.[92] It has been argued – most recently by Herman Kaptein – that investments in mechanisation through wind (and water and animal) energy continued to be cheaper in the Northern Low Countries than steam until the mid-nineteenth century and therefore made more sense as an investment choice. In this respect, early modern transitions to renewable mechanical energy preceded and hence retarded the adoption of fossil-fired steam in Holland.[93] In the Leiden textile industry, for example, wind-, water- and horse mills were employed for fulling, spinning and fabric pressing.

Yet, these path-dependent developments did not prevent certain sectors in the Northern Low Countries to invest in steam technology before the middle of the nineteenth century already.[94] Nor is it the case that in coal-rich regions traditional sources of power were quickly abandoned when the transition to steam had begun. In fact, much of the production process has long remained labour-intensive rather than labour-saving, even in the early stages of the industrial revolution. The first *indiënneries* (cotton printing factories) in eighteenth-century Ghent of Judocus Clemmen, Abraham Voortman and Frans de Vos employed several hundred labourers.[95] Likewise, the Leiden textile industry had known larger manufactories since the seventeenth century.[96] Furthermore, in those sectors where machine technology was installed traditional and modern forms of mechanisation have long co-existed. Previous research on the industrial use of watermills in England has showed that even in the core region of the early industrial revolution water power was more cost-effective than steam until at least the mid-nineteenth century.[97] This co-existence of old and new machine technology is evident from the 1806 probate inventory of the cloth producer Jan van Heukelom, whose son would in 1816 introduce the first steam engine in the Dutch textile industry. In the inventory of his factory is mentioned a horse mill, a textile press and several (man-operated) spinning jennies 'designed after the English mechanical practice'.[98] Also in Ghent the mechanisation process followed a hybrid pattern. The company of Valentijn van Loo – another early 'textile boss' in

[90] Smit, "De introductie van de stoomkracht", 529; SAG, Series K, Handel en nijverheid, no. 96.
[91] H.W. Lintsen, "Een land zonder stoom", in *Geschiedenis van de Techniek in Nederland: de wording van een moderne samenleving, 1800-1890*, edited by H.W. Lintsen (Zutphen: Walburg Pers, 1992-1995), VI, 51-63.
[92] Karel Davids, "Innovations in windmill technology in Europe, c. 1500-1800. The state of research and future directions of inquiry", *NEHA-Jaarboek* 66 (2003), 43-63.
[93] Herman Kaptein, *Nijverheid op windkracht: energietransities in Nederland, 1500-1900* (Hilversum: Verloren, 2017).
[94] Harry Lintsen, "Stoom als symbool van de industriële revolutie", *Jaarboek voor de Geschiedenis van Bedrijf en Techniek* 5 (1988), 337-353.
[95] Coppejans-Desmedt, *De Gentse textielnijverheid*, 451-4.
[96] Posthumus, *De geschiedenis van de Leidsche lakenindustrie*.
[97] J.W. Kanefsky, *The Diffusion of Power Technology in British History, 1760-1870* (unpublished PhD thesis, University of Exeter, 1979).
[98] GAL, Familiearchief (Siegenbeek) Van Heukelom, (1514) 1610-1928, no. 31.

Ghent – owned a '*machine à vapeur*', but also a '*machine à tisser*' and a '*machine à filer*', which were presumably hand-driven, as well as a '*moulin en bois*'.[99]

Most indications suggest that industrialists in Holland who invested in steam were as dependent upon coal as their competitors from Flanders. Although some attempts to produce steam engines powered by peat are known from the Twente area, there is no such evidence specifically for Leiden, nor does it appear to have been successful in the long run for the entire Northern Low Countries.[100] According to a Leiden document from 30 January 1827 trying to regulate the installation of steam engines, the city's cloth factories were powered by the 'heavy fire of coal'.[101] While most of the urban energy consumption was still derived from peat – especially for domestic heating and artisanal production – textile industrialists in Leiden and other Dutch towns probably invariably used coal to keep their engines running. It is telling, for instance, that the Leiden textile entrepreneur J.J. Krantz consistently used peat to heat his factory, office and home in the early nineteenth century, while he relied on more expensive coal to power his steam engines, as is clear from his accounts.[102] The need for coal among Dutch industrial entrepreneurs is also evident from the fact that all industries that made use of steam were largely exempted from the national coal excise of 1834-1864, which in all other cases heavily favoured the consumption of domestic peat by levying much heavier taxes on imported fuel.[103] In general, the Dutch government was highly favourable towards the industrial application of steam, especially from the 1830s onwards – while still maintaining its protectionist fuel policy as well.

Table 5. Relative share of industrial coal consumption in Ghent and Leiden, 1650-1850 (in %).

	Ghent		**Leiden**	
	Industrial coal	**Rest coal**	**Industrial coal**	**Rest coal**
1650	51	49	96	4
1700	72	28	96	4
1750	47	53	97	3
1800	11	89	68	32
1850	25	75	95	5

Sources: see methodological appendix.

It can be assumed that except for baking, linen bleaching and cloth dyeing most industries considered in this paper were coal burners. When building further on that assumption, we can assess the relative importance of industrial coal consumption within the urban economy. It becomes clear, then, from table 5 that industry was the most important user of coal in Leiden and in pre-1750 Ghent. This suggests that certain industries had already made the

[99] State Archives Ghent (hereafter: RAG), New notary archives, no. NOT639/62.
[100] J. Boessenkool, "De eerste stoommachine in de Twentse textielindustrie", *Textielhistorische Bijdragen* 4 (1963), 68.
[101] GAL, Stadsarchief van Leiden (Stadsbestuur III), 1816-1929, no. 4567.
[102] GAL, Archief van J.J. Krantz & Zoon te Leiden, 1797-1970, no. 692.
[103] J. Teijl, "Brandstofaccijns en nijverheid in Nederland gedurende de periode, 1834-1864", in *Lof der historie: opstellen over geschiedenis en maatschappij*, edited by J. van Herwaarden (Rotterdam: Universitaire Pers, 1973), 155-183.

energy transition to fossil fuel before the overall coal revolution in the Southern Low Countries (during the late eighteenth century) and in the Northern Low Countries (during the late nineteenth century). In other words, coal only took a true 'revolutionary' form when most of the population – i.e. households – had switched to it. But before that time, it was already consumed for industrial activity – in Ghent *and* in Leiden, where coal took a marginal but not insignificant part of the energy mix since the seventeenth century already. Despite the uneven distribution of the regional fortune in fuel acreage, industries like the brewing sector, distilling, sugar refining, soap boiling, glass making and the textile industry in seventeenth-, eighteenth- and nineteenth-century Holland – like their contemporaries in the Southern Low Countries – largely switched to coal as their primary source of energy. Before and during the early industrial revolution, coal was incorporated in the 'energy metabolism' of the Low Countries' industrial city.

Conclusions

This comparative study has tried to get better insight into the industrial consumers of energy, and in particular coal, in Ghent and Leiden during the long eighteenth century. The findings it has presented suggest that the proximity to coalfields was essential for industrial development – perhaps in the first instance, but not in the 'last instance'. While the availability of coal may have been the *primary* cause behind the divergent trajectories of early industrialisation in Ghent and late industrialisation in Leiden, it does not appear to have been the *ultimate* condition that triggered the industrial revolution. After all, for a 'country without coal', the Northern Low Countries surely had a widening range of industries that consumed significant amounts of the black fuel in the seventeenth to nineteenth centuries. Before the large-scale adoption of coal by the majority of consumers who were persuaded by shifting relative prices, specific industries had already followed earlier coal-burning trajectories in both Ghent and Leiden – even if coal did not (yet) provide the cheapest price for energy.

In this respect, the history of energy was not 'the secret history of industrialisation', as Rolf Peter Sieferle claimed.[104] Rather, the opposite was true. Perhaps, indeed, explanations for the intimate ('metabolic') relationship between coal and industrialisation should be found in the internal organisation of the involved industries themselves. The introduction of mechanising technologies could not have happened without the willingness of entrepreneurs to invest capital in a centralised production system, and hence without the availability of industrial capital. This centralisation process was already well under its way before the invention of steam – through traditional mechanical technology in the textile industry and through heat-intensive developments in such industries as glass making, sugar and salt refinery, soap boiling and brewing. Coal had the advantage, not only of producing higher energy levels, but also

[104] Rolf Peter Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution* (Cambridge: White Horse Press, 2001).

– and more importantly – of improving on storage compactness and handling time; hence, allowing to save in the labour needed to service a fire or to operate a machine.

Coal-fuelled technology, in other words, enabled the centralisation of the production process into a single space where labour and energy (capital) were integrated under one roof.[105] While in the Northern Low Countries capital was mostly concentrated in trade and finance, industrial entrepreneurs in the early modern Southern Low Countries started to actively interfere in the production process and gradually acquired the necessary capital to do so.[106] Maybe this difference between 'mercantile capital' in the North and 'industrial capital' in the South is exactly the reason why in Holland the industrialisation process was generally much less pronounced. But in those industries that had industrial capital – such as those in Leiden, where, as an exception to the Dutch rule, important parts of the textile industry had been centralised into manufactory production since the seventeenth century already – investments in coal technology would eventually follow. Less the result of a 'geographic accident', the consumption of coal for industrial development appears then to have been an integral part of an economic system based on the concentration of labour and capital. According to Wrigley, the connection between industrial capitalism and fossil energy was 'casual rather than causal'; it may very well have been the other way around.[107]

[105] Andreas Malm, *Fossil Capital: The Rise of Steam Power and the Roots of Global Warming* (London: Verso, 2016).
[106] Catharina Lis and Hugo Soly, "Different paths of development: capitalism in the Northern and Southern Netherlands during the late middle ages and the early modern period", *Review (Fernand Braudel Center)* 20:2 (1997), 211-242.
[107] Wrigley, *Continuity, Chance and Change*, 115.

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.[108] 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.

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.[109] Leiden at that time was renowned for its vibrantly coloured dyed cloth.[110] In both towns, the number 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 on 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).[111] 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.[112] In Ghent,

[108] Cavert, "Industrial coal consumption".
[109] 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)* (unpublished master thesis, University of Ghent, 1985), *Proeve*, 152-157 and Sabbe, *De Belgische vlasnijverheid*, II, 630.
[110] Cloth production data were derived from Posthumus, *De geschiedenis van de Leidsche lakenindustrie*, III, 930-931, 1098-1099.
[111] Jennifer Tann, "Fuel saving in the process industries during the industrial revolution: a study in technological diffusion", *Business History* 15:2 (1973), 157.
[112] Posthumus, *De geschiedenis van de Leidsche lakenindustrie*.

master bleachers produced about eight pieces a day; hence, each unit of production required about 1.7 GJ.[113]

2. Brewing

Production data on brewing are available for Leiden.[114] For Ghent I have used consumption data – assuming that all beer drunk in the city was also produced in the city.[115] 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.[116]

3. Baking

Baking data for both Ghent and Leiden were derived from consumption instead of production figures.[117] 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.[118] This means that it required about 0.26 GJ of energy to bake a ton of bread.

4. Distilling

Distilling was based on the consumption of brandy.[119] 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.[120]

5. Sugar refining

Sugar refinery started to develop in Ghent from the middle of the eighteenth century onwards, but it did not in 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

[113] Sabbe, *De Belgische vlasnijverheid*.
[114] Unger, *A History of Brewing in Holland*, 239.
[115] Van Daele, *Proeve*, 33-59; Vandenbroeke, "Voedingstoestanden te Gent", 147.
[116] Cavert, "Industrial coal consumption", 430.
[117] Ghent: Van Daele, *Proeve*, 19-27; Chris Vandenbroeke, "Voedingstoestanden te Gent tijdens de eerste helft van de 19de eeuw", *Belgisch Tijdschrift voor Nieuwste Geschiedenis* 1 (1973), 143. Leiden: GAL, city archives II, rekeningen van de tresorier ordinaris, nos. 7475-7516; GAL, city archives II, blaffaards van de tresorier ordinaris, nos. 9722-10095; GAL, city archives III, city accounts, nos. 3486-3533.
[118] Kaplan, *The Bakers of Paris*, 77.
[119] Ghent: Van Daele, *Proeve*, 62-70; Vandenbroeke, "Voedingstoestanden te Gent", 148. Leiden: GAL, city archives II, rekeningen van de tresorier ordinaris, nos. 7475-7516; GAL, city archives II, blaffaards van de tresorier ordinaris, nos. 9722-10095; GAL, city archives III, city accounts, nos. 3486-3533.
[120] Cavert, "Industrial coal consumption", 431.

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.[121] 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.[122] 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.[123]

6. 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.[124] Ghent, on the other hand, had developed a salt refining industry during the early modern period. Again, the data are based on consumption levels.[125] 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 consumption of salt.[126] Around that time the annual consumption of salt reached a level of almost 600 tons. This suggests that most salt produced in Ghent was also sold in the city itself. I have used the same ratio of energy input per economic output as for sugar refining.

7. Brick and lime making

Brick and lime were used in the building sector. In Ghent the use of bricks was submitted to a tax.[127] 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.[128] 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.[129] Cavert has suggested that the production of 100 million bricks cost about 14,000 tons of coal.[130] This means that it required c. 3.8 MJ of energy to fire one brick.

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[121] Philippe Moureaux, *La statistique industrielle dans les Pays-Bas autrichiens à l'époque de Marie-Thérèse: documents et cartes* (Brussesls: Palais des Académies, 1974-1981), 325.
[122] Faipoult, *Mémoire statistique*, 175
[123] Stein, *The French Sugar Business*, 132.
[124] De Vries and Van der Woude, *The First Modern Economy*, 419-420.
[125] Van Daele, *Proeve*, 91-99.
[126] Moureaux, *La statistique industrielle*, 324-325.
[127] Van Daele, *Proeve*, 121-128.
[128] De Vries and Van der Woude, *The First Modern Economy*, 304-305.
[129] 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.
[130] Cavert, "Industrial coal consumption", 434.

8. Soap boiling

Both Leiden and Ghent produced soap.[131] The data behind soap boiling are again, however, based on consumption estimates.[132] A study on 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.[133]

9. 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.[134] Eleanor Godfrey's study on English glass making estimated that it took 6 tons of coal (or 162 GJ of energy) to make 1 ton of glass.[135]

10. Pottery

While Delft was famous for its majolica production during the early modern period, other Holland cities such as Leiden had pottery industries as well. The city is known to have had five potteries in 1674.[136] 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.[137] By 1764 there was only one pottery left.[138] 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.[139]

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[131] 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: Nederlandsche Maatschappij voor Nijverheid en Handel, 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.

[132] Ghent: Van Daele, *Proeve*, 164-168. Leiden: GAL, city archives II, rekeningen van de tresorier ordinaris, nos. 7475-7516; GAL, city archives II, blaffaards van de tresorier ordinaris, nos. 9722-10095; GAL, city archives III, city accounts, nos. 3486-3533.

[133] L. Gittins, "Soapmaking in Britain, 1824-1851: a study in industrial location", *Journal of Historical Geography* 8:1 (1982), 34.

[134] Data were derived from Van Heesvelde, "De glasnijverheid te Gent" (Ghent) and GAL, Index Gilden, namen van meesters, leerlingen enz. 1574-1812; Klein, "Nederlandse glasmakerijen" (Leiden).

[135] Godfrey, *The Development of English Glassmaking*, 194.

[136] Marie-Cornélie Roodenburg, *De Delftse pottenbakkersnering in de gouden eeuw (1575-1675). De produktie van rood pottengoed* (Hilversum: Verloren, 1993), 123.

[137] Johan Dambruyne, *Corporatieve middengroepen: aspiraties, relaties en transformaties in de 16de-eeuwse Gentse ambachtswereld* (Gent: Academia Press, 2002), 44, 755.

[138] Moureaux, *La satistique industrielle*, 321.

[139] Lorna Weatherill, *The Growth of the Pottery Industry in England, 1660-1815* (New York: Garland, 1986), 440-441, 452.

11. 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 fuel (particularly 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 spinneries, calico printing companies and cotton weaving factories.[140] In Leiden engines were mostly deployed for the production of woven cloth and other woollen textiles.[141] 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 were counted.[142] Fuel requirements per engine per year were based on the estimates of Von Tunzelmann who figured that one steam engine annually consumed 22 tons of coal per horsepower – assuming that each engine had an average power of 16 hp.[143]

[140] Coppejans-Desmedt, *De Gentse textielnijverheid*, 175 ff.
[141] Smit, "De introductie van de stoomkracht", 527-535.
[142] Van Neck, *Les débuts*, 824-827; Smit, "De introductie van de stoomkracht", 529.
[143] G.N. Tunzelmann, *Steam Power and British Industrialization to 1860* (Oxford, 1978), 67-70.