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RESEARCH ARTICLE

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

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Abstract
This article presents a comparative study of the industrial energy consumption in Ghent and Leiden, from the seventeenth to nineteenth centuries. It asks whether or not industrial development depended on the availability of coal. Whereas the Southern Low Countries had recourse to cheap coal from the beginning of the eighteenth century onwards, the Northern Low Countries remained trapped in its 'proto-fossil' trajectory based on peat, lacking a full fossil-fuel transition. By using production data to estimate the fuel consumption by industry, it is argued that energy divergences did not matter for industrialization. Both in Ghent *and* in Leiden, industries such as brewing, sugar refining, glass making and textile production had already largely switched to coal by the end of the seventeenth century. Explanations for these early coal-burning trajectories should be found, not in the 'lucky' location of coal supplies, but in the demand and organization of coal-specific industry itself.

The importance of fossil energy in the history of the industrial revolution remains the subject of ongoing debate.[1] Indeed, energy has been placed by historians at the heart of the industrialization process in eighteenth- and nineteenth-century north-west Europe. Expanding on earlier ideas produced by Phyllis Deane, David Landes and Fernand Braudel, among others, and building on the empirical evidence on the British coal industry of Michael W. Flinn, Roy Church and John Hatcher, E.A. Wrigley, in particular, has fundamentally shaped the early modern history of energy.[2]

[1]For a recent overview, see A. Kander, P. Warde and P. Malanima, *Power to the People: Energy in Europe over the Last Five Centuries* (Princeton, 2013).

[2]P. Deane, *The First Industrial Revolution* (Cambridge, 1965); D.S. Landes, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present* (Cambridge, 1969); F. Braudel, *Civilization and Capitalism, 15th–18th Century*, vol. I: *The Structures of Everyday Life* (London, 1985); M.W. Flinn, *The History of the British Coal Industry*, vol. II: *1700–1830: The Industrial Revolution* (Oxford, 1984); R. Church, *The History of the British Coal Industry*, vol. III: *1830–1913: Victorian Pre-Eminence* (Oxford, 1986); J. Hatcher, *The History of the British Coal Industry*, vol. I: *Before 1700: Towards the Age of Coal* (Oxford, 1993).

According to Wrigley, an energy revolution in the use of fossil fuels played a pivotal role in determining the ability of economies to generate modern growth.[3] 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 industrial revolution. Unlike the flow of energy captured in food and firewood, which were the most important sources of energy in organic economies, fossil fuels supplied a stock of energy accumulated in underground stores of minerals, providing economies that were otherwise constrained by the availability of land with the necessary energy inputs to alleviate the natural limits to growth. Although the idea that coal (and later gas and oil as well) mattered primarily, if not only, to sustain economic growth in the long run has been questioned by various historians,[4] the resource-intensive view of industrialization has proven highly influential in the debate on the great divergence in the world and the little divergence in Europe.[5]

Of course, energy can never be an autonomous explanation by itself. Energy historians have always viewed the importance of the fossil-fuel transition in conjunction with other variables. In his 'high wages, cheap energy' model of the British industrial revolution, Robert C. Allen emphasized the role of coal as a labour-saving, rather than a land-saving technology.[6] The unique combination of high wages and cheap energy prices created the incentive 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.[7] While coal initially helped to augment the pressure on land during the seventeenth and eighteenth centuries, it was only in a later phase that it enabled the British economy to realize substantial economic growth, when coal, through scientific, institutional and social development, could be used as a substitute for labour as well. Also from a world-historical perspective, scholars such as Kenneth Pomeranz and Prasannan Parthasarathi have stressed that coal (and colonies) was not just a European windfall in the global economic divergence of the last couple of centuries. Fossil fuels had to be found, explored and exploited, and this could only be done under the 'right' circumstances – that is, the role played by technological innovation, political economy and changes in con-

[3]E.A. Wrigley, *Continuity, Chance and Change: The Character of the Industrial Revolution in England* (Cambridge, 1988); *idem*, *Energy and the English Industrial Revolution* (Cambridge, 2010); *idem*, *The Path to Sustained Growth: England's Transition from an Organic Economy to an Industrial Revolution* (Cambridge, 2016).

[4]Most notably perhaps by McCloskey and Mokyr who argued for the cultural origins of the industrial revolution: D.N. McCloskey, *Bourgeois Dignity: Why Economics Can't Explain the Modern World* (Chicago, 2010); J. Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress* (New York, 1990).

[5]K. Pomeranz, *The Great Divergence: China, Europe, and the Making of the Modern World Economy* (Princeton, 2000); P. Malanima, 'The energy basis for early modern growth, 1650–1820', in M. Prak (ed.), *Early Modern Capitalism: Economic and Social Change in Europe, 1400–1800* (London and New York, 2001), 51–68.

[6]R.C. Allen, *The British Industrial Revolution in Global Perspective* (Cambridge, 2009); *idem*, 'Why the industrial revolution was British: commerce, induced invention, and the scientific revolution', *Economic History Review*, 64 (2011), 357–84.

[7]P. Malanima, 'Energy consumption in England and Italy, 1560–1913. Two pathways toward energy transition', *Economic History Review*, 69 (2016), 78–103.

sumer demand.[8] While these models do provide important clues on the chronology of Britain's coal transition – explaining why it was not until the eighteenth century that the British utilized what had been under their nose for all that time – they still consider fossil energy as a *sine qua non* for industrialization. For Malanima and Allen, the availability of coal explains why Britain industrialized and why Italy (among other European countries) did not. For Pomeranz and Parthasarathi, it explains why, in a global perspective, the West grew rich and the rest remained poor.

Although the energy revolution thesis has crucially – and rightfully so – provided further scholarly material to fully abandon the old Eurocentric narrative on the industrial revolution – establishing the importance of 'chance'[9] in the making of economic success and reinterpreting Europe's exceptionalism as the story of a 'fortunate freak'[10] – it has its own paradigmatic obstacles to be overcome. Much of this historiography is indeed still firmly rooted in a neoclassical-economic terminology that departs from the idea of structural poverty as the 'normal state of affairs' in history, which could eventually be altered by an energy revolution to fossil fuels. This is perhaps most visible in older literature, when in the early 1960s Carlo M. Cipolla, for instance, did not hesitate to put energy forward as the most important 'limiting factor' that kept economic and demographic growth in check in pre-industrial societies.[11] But also in recent energy historiography the spirit of the classical economists remains strongly present – most explicitly so in Wrigley's account of the English industrial revolution.[12] Even though John U. Nef, the founding father of British energy history, had stressed in his peerless work from 1932 the relationship between coal and capitalism, this idea has largely been refuted ever since.[13] Coal is now widely seen as a 'logical' remedy, historically, for traditional Malthusian and Ricardian problems of scarcity. In such a reading of economic development, the industrial revolution becomes little more than a lucky accident of geology in which coal, as a gift of nature, gave economies the final spark to industrialize. Industrialization *must* have been fossil-fuel based, or it would not have been at all.

But was coal really necessary for industrial development? The current most dominant interpretations of the historical relationship between energy and industrialization tend to neglect the role of the 'inner' dynamic of the organization of industry itself. Looking at energy endowments to understand economic progress indeed implies that the constraints that prevented growth were somehow 'external' to industrialization and that coal was simply 'out there' – at least in those countries that were blessed by it – waiting to be used as a technical solution to escape the curse of poverty. In recent years, however, historians and social scientists have

[8]Pomeranz, *The Great Divergence*; P. Parthasarathi, *Why Europe Grew Rich and Asia Did Not. Global Economic Divergence, 1600–1850* (Cambridge, 2011).

[9]Wrigley, *Continuity, Chance and Change*, 113–15.

[10]Pomeranz, *The Great Divergence*, 207.

[11]C.M. Cipolla, *The Economic History of World Population* (Harmondsworth, 1962). For a more recent reinterpretation of the 'limiting factor' in pre-industrial economies, see P. Malanima, 'The limiting factor: energy, growth, and divergence, 1820–1913', *Economic History Review*, 73 (2020), 486–512.

[12]In his final and most comprehensive book on the matter, he devoted an entire chapter to the classical economists: Wrigley, *The Path to Sustained Growth*, ch. 2.

[13]J.U. Nef, *The Rise of the British Coal Industry* (London, 1932).

adopted a more holistic point of view to emphasize the historical interconnectedness between 'energy' and 'economy', in which resource endowments are considered not as a static factor in human progress but as connected to a single process of coevolution between society and environment. The dialectic relation between energy (or nature, more broadly) and society is perhaps best expressed in the concept of 'metabolism' – a term that was first applied to society by Karl Marx but that has since been elaborated further only from the 1990s onwards, in social ecology especially.[14] In socio-ecological studies, 'social metabolism' is defined as 'the particular form in which societies establish and maintain their material input from and output to nature; the mode in which they organize the exchange of matter and energy with their natural environment'.[15] In historiography, Stephen Mosley and, more recently, William M. Cavert – both pioneering in writing an urban-environmental history of energy – have shown how coal in early modern London and nineteenth-century Manchester could only be implemented on a massive scale when it became a 'natural' part of urban culture.[16] From a more historico-theoretical and explicitly eco-Marxist perspective, Jason W. Moore argued that global economies – or 'world-ecologies' – have acted as ways of environment-making according to which energy and other 'natures' (including labour, food and raw materials) are appropriated and put to work within a system of production.[17] Tracing the roots of steam power, Andreas Malm applied this eco-Marxist thought to the case of Britain, noting that it was not industrial growth per se but the logic of capital more specifically that drove the ever-growing consumption of fossil fuels.[18] Rather than interpreting coal as a *precondition for* economic progress, these new approaches of research have viewed the rise of fossil energy as *resulting from* the structures in the economy itself.

In this article, I wish to make an empirical contribution to the debate on the relationship between energy and industrialization, by performing 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 offers a curious case-study in the history of energy. As one of the most economically developed and urbanized regions of Europe, it has been credited with an exceptional energy trajectory throughout much of its history. Meanwhile, important regional differences in economic development long existed within the Low Countries 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

[14]On a genealogy of the concept, see J.B. Foster, *Marx's Ecology: Materialism and Nature* (New York, 2000).

[15]M. Fischer-Kowalski, 'Society's metabolism', in M. Redclift and G. Woodgate (eds.), *International Handbook of Environmental Sociology* (Northampton, MA, 1997), 120.

[16]S. Mosley, *The Chimney of the World: A History of Smoke Pollution in Victorian and Edwardian Manchester* (Cambridge, 2001); W.M. Cavert, *The Smoke of London: Energy and Environment in the Early Modern City* (Cambridge, 2016).

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

[18]A. Malm, *Fossil Capital: The Rise of Steam Power and the Roots of Global Warming* (London, 2016).

[19]J. Mokyr, *Industrialization in the Low Countries, 1795–1850* (New Haven, 1976).

industrialize outside the British Isles.[20] The Northern Low Countries, on the other hand, was viewed as a prototypical case of an 'advanced organic economy': while the Dutch Republic had profited during its Golden Age from large deposits of peat, it failed to make 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 emphasize 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. Industrialization in the Northern Low Countries was generally less rapid, but here as well cities like Leiden and Tilburg were important exceptions to the rule.

Within this framework of regional divergence, the central question asked here is whether or not industries in the two cities under scrutiny were constrained by the energy basis of their respective economies. Looking at the industries behind the cities' energy consumption can tell us more about the presumed necessity of available coalfields to industrialization. If energy endowments were indeed crucial, then we would expect the degree of industrial energy needs to have been higher in Ghent, where there was an early transition to coal. If not, and coal proves to have been integrated in Leiden manufacture as well – even in the absence of cheap availability of the fuel – then the roots of coal-fired production must lie in the nature of the involved industries themselves. Therefore, it will also be asked what types of industries specifically burned coal and why they did so – and why they did not burn any other fuel. Methodologically, this study draws inspiration from Cavert, who studied industrial coal consumption in early modern London in this same journal, using production data – obtained on the basis of taxes levied on the relevant industries' products – and, then, applying to them a fixed ratio of fuel amounts needed to make one unit of production.[22] This ratio accounts for the energy spent inside the workshop itself; the energy required for the transport and production of the fuels consumed is excluded. Indeed, my goal is to identify the demand for energy by industry and how this shaped transitions in the supply of energy, rather than the other way around. Regionally divergent energy supplies serve here as a background against which to test how urban industries adapted to or, conversely, prepared the way for fossil-fuel trajectories. The details of the methodology are discussed in the appendix, but it should suffice here to note that working with a fixed energy/output ratio is of course only a very rudimentary form of quantification, since it does not take potential improvements or local variances in energy efficiency into account. It does allow, however, to systematically quantify an important issue that remains underexplored: industry's proportion of urban energy consumption before and during the early industrial revolution in

[20] H. Van der Wee, 'The industrial revolution in Belgium', in M. Teich and R. Porter (eds.), *The Industrial Revolution in National Context: Europe and the USA* (Cambridge, 1996), 64–77.

[21] J. Luiten van Zanden, 'Industrialization in the Netherlands', in Teich and Porter (eds.), *The Industrial Revolution*, 78–94.

[22] W.M. Cavert, 'Industrial coal consumption in early modern London', *Urban History*, 44 (2017), 424–43.

one of the core regions in Europe at the time. This quantitative approach will be complemented by a more qualitative discussion to identify those industries that were responsible for the adoption of coal. After setting the scene in the first section, which discusses the chronology of energy transition and economic divergence in the Low Countries, this article will address the main research question, first by looking at all fuel-intensive industry (the second section) and then by zooming in on those industrial sectors that were coal-specific (the third section) – in Ghent and Leiden, from the seventeenth to nineteenth centuries.

Energy transitions and economic divergence in the Low Countries

As in the debate on the prime movers of the British industrial revolution, access to mineral energy has appeared to historians as a plausible explanation for the Low Countries' conundrum of divergent development as well – witness the 'energy debates' on the role of fuel accessibility in the economies of 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'.[23] Although little of his estimates survived the test of time – Richard W. Unger, for instance, suggested that de Zeeuw had considerably underestimated the import of coal in early modern Holland – most historians still maintained that '[m]uch of the industrial growth depended on the use of fossil fuels, principally peat but increasingly coal'.[24] Meanwhile, historians also highlighted the role of energy in the Southern Low Countries. The pioneering research of Chris Vandenbroeke indicated that the nascent energy crisis in the Austrian Netherlands, 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 – which eventually became the principal energy source to power the cotton, woollen and iron industries in the early industrial nation of Belgium.[25]

When zooming in on the historical composition of the energy mix in the two cities at hand, the general differences between the Northern and Southern Low Countries are reconfirmed.[26] While Ghent experienced a radical shift towards

[23]J.W. de Zeeuw, 'Peat and the Dutch Golden Age: the historical meaning of energy-attainability', *AAG Bijdragen*, 21 (1978), 3–31. Earlier roots of the economic reliance on peat in Holland have recently been traced in C. Cornelisse, *Energiemarkten en energiehandel in Holland in de late middeleeuwen* (Hilversum, 2008).

[24]R.W. Unger, 'Energy sources for the Dutch Golden Age: peat, wind, and coal', *Research in Economic History*, 9 (1984), 221–53. 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, 1995); and J.L. 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), 484–99.

[25]C. Vandenbroeke, 'Zuinig stoken. Brandstofverbruik en brandstofprijzen in België en Frankrijk sinds de 15e eeuw', *Economisch- en Sociaal-Historisch Jaarboek*, 51 (1988), 93–125; *idem*, 'De problematiek van de energievoorziening in de zuidelijke Nederlanden en inzonderheid in Vlaanderen (15de–19de eeuw)', *Revue Belge de Philologie et d'Histoire*, 73 (1995), 102–17.

[26]The figures on the energy regime, including its prices, of Ghent and Leiden in the seventeenth to nineteenth centuries are discussed in depth elsewhere: W. Ryckbosch and W. Saelens, 'Fuelling the urban

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 the middle of the seventeenth century coal – mostly from the Borinage area which reached Ghent via the Scheldt river – delivered approximately 15 to 20 per cent of the energy required – a percentage that would remain stable until *c.* 1750. Besides firewood, food for human labour was the other major source of energy of the pre-industrial regime, reaching about 30 per cent before 1800. 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 by the beginning of the seventeenth century, it was around 1750 that a true 'energy revolution' occurred in that city when the price of coal fell below that of fuelwood (firewood and charcoal). 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' phase.

The Leiden economy followed a more fuel-intensive path of energy consumption during the seventeenth and eighteenth centuries. Food and feed (and thus human and animal labour) played a minor role – reaching around 15 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 *c.* 80 per cent in 1700, while their combined share in Ghent reached only *c.* 65 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. In the seventeenth century, Leiden had already achieved the status of an advanced energy economy – benefiting from plentiful supplies of energy before industrialization proper. The city was a typical example of Holland's 'proto-fossil' trajectory in which cheap peat to a great extent supplemented soil-dependent energy sources such as wood and food – very much like coal would do in a later stage. In the middle of the seventeenth century, during Holland's phase of 'peak peat', the brown fuel supplied about three-quarters of the energy in Leiden's urban metabolism. Coal, on the other hand, remained expensive. 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 first half of the nineteenth century. After 1815, the consumption of coal did indeed 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.[27] By the time of Belgian independence in 1830, however, the access of the Dutch to coal from the south was blocked off once again. Only around 1900 did coal become the main source of energy in the Netherlands.[28]

In Ghent, soon to become the 'Manchester of the Continent', the blessing of coal arrived at a time of large-scale economic expansion. After having been a major

economy: a comparative study of energy in the Low Countries, 1600–1850', *Economic History Review* (2022; published in early view).

[27]J.L. van Zanden and A. van Riel, *The Strictures of Inheritance: The Dutch Economy in the Nineteenth Century* (Princeton, 2004), 206–10.

[28]B. Gales, A. Kander, P. Malanima and M. Rubio, 'North versus south: energy transition and energy intensity in Europe over 200 years', *European Review of Economic History*, 2 (2007), 224.

producer of woven cloth in the later Middle Ages and after experiencing a period of post-medieval decline,[29] the expansion of industrial production of linen and cotton textiles in the eighteenth and nineteenth centuries turned Ghent into one of the first industrializing cities on the European mainland.[30] The output of (mechanized) cotton production especially increased at an astonishing rate.[31] 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 characterized by an early factory-like organization with manufacturers (*fabrikanten*) employing several wage labourers.[32] By the end of the seventeenth century, the Leiden cloth industry had reached its peak, after which a steady decline followed – though a class of manufacturers always remained active in the city.[33] Nonetheless, Leiden remained the most important textile city in the Netherlands, together with Haarlem and Tilburg, until at least the middle of the nineteenth century.[34] But despite its relative economic resilience in the production of woollen cloth, Leiden never became an industrialized hub like its counterpart in Flanders.

The economic cycles of both cities are clearly reflected in their population histories. 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.[35] 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 population had reached an all-time low, when there were *c.* 30,000 inhabitants within the city walls.[36] Only from the 1830s onwards did the population of Leiden experience a modest rise, but it would never again catch up

[29]M. Boone, 'L'industrie textile à Gand au bas moyen âge ou les resurrections successives d'une activité réputée moribonde', in *idem* and Walter Prevenier (eds.), *La draperie ancienne des Pays-Bas. Débouchés et stratégies de survie, 14e–16e siècles* (Leuven, 1993), 122–35.

[30]J. Hannes, 'Industrialization without development. Some aspects of the history of Ghent', in P. Kooij and P.H. Pellenbarg (eds.), *Regional Capitals: Past, Present, Prospects. Ghent, Groningen, Münster, Norwich, Odense, Rennes* (Assen, 1994), 9–18.

[31]H. Coppejans-Desmedt, 'De Gentse textielnijverheid van 1795 tot 1835: het proces van mechanisering in zijn economische gevolgen', University of Ghent Ph.D. thesis, 1958.

[32]N.W. Posthumus, *De geschiedenis van de Leidsche lakenindustrie* (The Hague, 1939).

[33]H.A. Diederiks, 'Beroepsstructuur en sociale stratificatie in Leiden in het midden van de achttiende eeuw', in H.A. Diederiks, D.J. Noordam and H.D. Tjalsma (eds.), *Armoede en sociale spanning: sociaal-historische studies over Leiden in de achttiende eeuw* (Hilversum, 1985), 45–68.

[34]M. Jansen, *De industriële ontwikkeling in Nederland 1800–1850* (Amsterdam, 1999).

[35]H. Van Werveke, *De curve van het Gentse bevolkingscijfer in de 17e en de 18e eeuw* (Brussels, 1948); P. Deprez, 'Het Gentse bevolkingscijfer in de tweede helft van de achttiende eeuw', *Handelingen der Maatschappij voor Geschiedenis en Oudheidkunde te Gent*, 11 (1957), 177–95; O. 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, 1902).

[36]D.J. Noordam, 'Demografische ontwikkelingen', in R.C.J. van Maanen (ed.), *Leiden: de geschiedenis van een Hollandse stad. Deel 2: 1574–1795* (Leiden, 2004), 43–53; H.D. Tjalsma, 'De bevolking', in R.C.J. van Maanen (ed.), *Leiden: de geschiedenis van een Hollandse stad. Deel 3: 1795–1896* (Leiden, 2004), 41–51.

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. In Ghent, firewood became expensive and coal became cheap; in Leiden, coal remained expensive and peat remained cheap. Over the course of the eighteenth and nineteenth centuries, the Malthusian–Ricardian advantages in the Low Countries – in terms of cheap fuel availability – seem to have shifted from the North to the South.

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? Although it would take until the invention of the steam engine to finally turn advanced organic economies into proper mineral economies, early coal (or peat) economies could already benefit from the new energy opportunities that fossil fuels provided before large-scale industrialization 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'.[37] 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.[38] 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'.[39]

As discussed in the methodological appendix, the amount of fuel (measured in gigajoules, GJ) consumed by the most important heat-intensive crafts in Ghent and Leiden over the course of the seventeenth to nineteenth century were calculated by gathering production estimates and multiplying these with a predetermined requirement of energy input per unit of production per industry.[40] The industrial activities under consideration are textile bleaching and dyeing, brewing, bread baking, distilling, salt and sugar refining, brick and lime making, soap boiling, 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 calculations given in Tables 1 and 2 account for a minimal amount of the total industrial fuel consumption in Ghent and Leiden.

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, respectively, of

[37] de Zeeuw, 'Peat and the Dutch Golden Age', 23.
[38] Hatcher, *The History of the British Coal Industry*, 458.
[39] Wrigley, *Energy and the Industrial Revolution*, 41.
[40] See methodological appendix.

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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: The figures account for 10-year averages around the reference year. Figures between brackets were extrapolated.
Sources: For the numbers behind the industrial energy consumption, see the methodological appendix. For the total energy volumes, see Ryckbosch and Saelens, 'Fuelling the urban economy'.

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
Energy per capita	36	22	25	26	45

Note: The figures account for 10-year averages around the reference year. Figures between brackets were extrapolated.
Sources: For the numbers behind the industrial energy consumption, see the methodological appendix. For the total energy volumes, see Ryckbosch and Saelens, 'Fuelling the urban economy'.

firewood, 10,000 and 24,000 tons of peat, or 6,000 and 15,000 tons of coal that were spent yearly in industrial applications. These numbers remained fairly stable and were significantly higher in Leiden than in Ghent up until the beginning of the nineteenth century. Total per capita fuel energy levels (both for industrial and domestic uses) 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 paths to be followed in Holland.

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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 sectors accounted for 54 to 62 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 total production 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. In the early modern period, Leiden was a famous producer of high-quality dyed cloths,[41] 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.[42] It comes as no surprise, then, that bleachers and dyers needed high amounts of fuel to heat the vats in which wool, linen, cotton or silk textiles were scoured.

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.[43] Similarly, in his case-study of Parisian bakers in the eighteenth century, Steven L. Kaplan found that 'wood and wheat were inseparably linked'.[44] Because of their importance in feeding the city, the guilds of bakers and brewers had already gained a lot of political power since the late Middle Ages. 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.[45]

Glass makers consumed a fair share of fuel as well. A guild of glass makers existed in Leiden from 1618 until 1812.[46] 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.[47] Glass makers in both towns mostly produced simple bottles, but

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

[42]E. Sabbe, *De Belgische vlasnijverheid*, 2 vols. (Kortrijk, 1975); J. Bastin, 'De Gentse lijnwaadmarkt en linnenhandel in de XVIIe eeuw', *Handelingen der Maatschappij voor Geschiedenis en Oudheidkunde te Gent*, 21 (1967), 131–62.

[43]J. Radkau, *Wood: A History* (Cambridge, 2012), 94–5.

[44]S.L. Kaplan, *The Bakers of Paris and the Bread Question, 1700–1775* (Durham, NC, 1996), 76.

[45]H. Soly, 'De economische betekenis van de zuidnederlandse brouwindustrie in de 16e eeuw. Problematiek', *Studia Historica Gandensia*, 179 (1973), 97–117; S. Gilté, 'Het Brugse bakkersambacht in de nieuwe tijden', University of Ghent MA thesis, 1996; R.W. Unger, *A History of Brewing in Holland, 900–1900: Economy, Technology and the State* (Leiden, 2001); K. Davids, *The Rise and Decline of Dutch Technological Leadership: Technology, Economy, and Culture in the Netherlands, 1350–1800* (Leiden, 2008), 143, 468–9.

[46]Regionaal Archief Leiden (Regional Archives Leiden, hereafter RAL), Gilden, namen van meesters, leerlingen enz. 1574–1812.

[47]P. Van Heesvelde, 'De glasnijverheid te Gent, 1693 – ca. 1730', *De Oost-Oudburg*, 27 (1990), 75–6.

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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	8	14	10	9	2
Baking	1	1	1	1	0
Distilling	2	2	1	3	1
Salt	21	17	11	5	2
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.

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	2	1
Distilling	2	2	2	2	1
Brick and lime	4	6	3	4	3
Soap	6	6	9	16	10
Glass	7	8	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.

occasionally also fabricated window glasses and mirrors. The industry was capital-intensive, with high costs for raw materials, fuels and infrastructure. In the middle of the seventeenth century, fuel consumption for glass making accounted for about 13 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 fuel consumed by industry.

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.[48] 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 that were placed above a stokehold – using *c*. 22 per cent of the industrial energy consumption around 1650. Salt refiners

[48] G. Deseijn, 'Zoutproductie in Gent, eerste en oudste geïndustrialiseerde stad van Vlaanderen (1750–1900)', *Tijdschrift voor Industriële Cultuur*, 67 (1999), 19.

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produced crude salt as well as washing soda or *sel-de-soude*. Companies therefore often specialized in the refining of both salt and soap. 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.[49] Similarly, sugar refining started to develop in Ghent from the middle of the eighteenth century onwards, 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* 13 sugar refineries in Ghent that collectively accounted for 33 per cent of all industrial fuel consumption.[50] Sugar cane was imported from the New World and reached Ghent via the Coupure canal, which was constructed in 1751,[51] enabling the sugar industry to grow exponentially and to meet the growing demand for sweetness of the eighteenth-century private consumer.[52] Finally, in a pre-industrial context, fuel energy was also crucial for some niche sectors such as distilling, brick and lime making and pottery production.

Despite the importance of (fossil) fuel for industrial production before the industrial revolution, it was only around the turn of the nineteenth century, with the introduction of steam power, that the relationship between energy and industry would change profoundly. Since the steam engine allowed for the conversion of the heat energy contained in fossil fuels into mechanical energy, a growing number of manufacturing sectors could now follow an energy-intensive (and labour-saving) path of growth. This pursuit of energy as a source of motion was mostly evident in the production of textiles, particularly so in the cotton industry – 'the wonder industry of the Industrial Revolution'.[53] In Ghent, the first steam engines found their way to the textile industry in the closing years of the eighteenth century.[54] From the 1780s onwards, cotton printing became the city's largest industry and soon employed thousands of labourers. In cotton spinning, perpetuals and jennies had already been in use before 1795,[55] but mechanization on a larger scale began when the industrialist Lieven Bauwens smuggled a spinning mule and a Newcomen engine from Manchester to Ghent in 1797.[56] By 1810, there were 4 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.[57] By then, steam-powered factories accounted for 87 per cent of all the fuel consumed by industry. The early mechanization of the

49 J. de Vries and A. van der Woude, *The First Modern Economy: Success, Failure and Perseverance of the Dutch Economy, 1500–1815* (Cambridge, 1997), 419–20.

50 G. Faipoult, *Mémoire statistique du Département de l'Escaut*, ed. P. Deprez (Ghent, 1960; orig. publ. 1804), 175.

51 G. Deseijn, *Bouwen voor de industrie: een verkenning in het Manchester van het vasteland* (Ghent, 1989), 224.

52 S.W. Mintz, *Sweetness and Power: The Place of Sugar in Modern History* (New York, 1985).

53 Allen, *The British Industrial Revolution*, 182.

54 A. Van Neck, *Les débuts de la machine à vapeur dans l'industrie belge: 1800–1850* (Brussels, 1979), 77ff and 101ff.

55 Coppejans-Desmedt, 'De Gentse textielnijverheid', 151–2.

56 J. 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, 1976), 208–67.

57 Van Neck, *Les débuts*, 824–7.

textile industry in Ghent stood in contrast to the situation in Leiden, where industrial mechanization not only happened at a later stage but where it also was much less profound. In the Dutch city, 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.[58]

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 former city, 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 in Ghent rose to a yearly average of 60 GJ. In Leiden, 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 the city reached in the mid-seventeenth century, it still accounted for a renewed increase after a long period of decline that, as in Ghent, was mostly driven by steam-powered manufacture – reaching 66 per of all the energy consumed by industry. This increase in fuel demands was all the more apparent when viewed in relation to population changes, as the per capita energy consumption in Leiden increased to 53 GJ in or around the year 1850. Despite the differences between the two cities, it is clear that both Ghent and Leiden over time required a growing flow of energy to sustain their urban activity.

Industrial coal-burning trajectories

At first glance, the hypothesis that coal was indeed crucial for industrialization may seem confirmed. Initially, peat had been benficial to the growth of heat-intensive industry in early modern Leiden, but did not eventually lead to industrial mechanization in the eighteenth and nineteenth centuries – at least not in the order of magnitude as that of Ghent. There, the transition to coal around 1750 was indeed quickly followed by a second-phase transition of industrialization in which fossil energy became not only land-saving but also labour-saving through the adoption of coal-fired 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. The relationship between high coal consumption and high industrial production should not be overstated. In fact, when looking at the relative share of industrial fuel consumption within the cities' 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. 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

[58]C.B.A. Smit, 'De introductie van de stoomkracht in Leiden', in J.W. Marsilje (ed.), *Uit Leidse bron geleverd* (Leiden, 1989), 529.

of 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 per cent of coal consumption was by the household rather than the industrial economy.[59] This gives additional empirical support to earlier observations by Hatcher and Allen that Britain's early transition to coal must have depended less on the industry's adoption of the fuel than on how ordinary households 'learned to heat a house with coal'.[60] Both the transition to coal in Ghent and the continued attachment to peat in Leiden could only have been made possible 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 shifted – could new types of energy be widely adopted and the transformation from one energy economy to another be completed. Most energy in Ghent and Leiden during the long eighteenth century was simply not used to power industry but rather served the comfort of urban consumers.[61]

While industrial demand for fossil fuel played a marginal role in the Low Countries' energy transition throughout the entire period studied, this does not of course 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 the earlier consumption of coal was directed at specific industrial needs. In the traditional textile sector, bleachers and dyers had 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 second half of the eighteenth century, 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.[62] 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.[63] 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.[64] In Leiden, peat was the obvious choice for dyers: it was cheaper and burned much more cleanly 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.[65] Likewise,

[59]Cavert, 'Industrial coal consumption'.

[60]Hatcher, *The History of the British Coal Industry*, 409ff; Allen, *The British Industrial Revolution*, 90ff.

[61]W. Saelens, 'The comforts of energy? Consumer culture and energy transition in eighteenth-century Gent and Leiden (1650–1850)', University of Antwerp and Vrije Universiteit Brussel Ph.D. thesis, 2021.

[62]Sabbe, *De Belgische vlasnijverheid*, vol. II, 50–4.

[63]C. Verbruggen, *De stank bederft onze eetwaren: de reacties op industriële milieuhinder in het 19de-eeuwse Gent* (Ghent, 2002), 19–20.

[64]Stadsarchief Gent (City Archives Ghent, hereafter SAG), Series 332, Minuten van staten van goederen, no. 776/13.

[65]N.W. Posthumus, *Bronnen tot de geschiedenis van de Leidsche textielnijverheid, 1333–1795*, 6 vols. (The Hague, 1910–22), vol. VI, 668–71.

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 charcoal as their fuel of choice, which produced high temperatures but came without the foul smoke of fossil energy.[66]

Other industrial sectors had much closer ties to the coal trade. From their very beginning, the salt and soda industries had always been highly dependent on the import of coal, which provided the high temperatures required to boil brine over large heated pans.[67] It was 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, who argued that the 'green, plentiful smoke or fume, mixed with the excessive and heavy soot' would form too great a danger for the environment.[68] For similar reasons as in salt refining and soap boiling, sugar refining depended strongly on the intensive energy of coal fuel.[69] Coal produced very high temperatures that simply could not be achieved by burning wood or peat. Although salt, sugar and soap refineries were often small enterprises, employing two to three labourers, they were based on a manufacture-like organization, requiring high quantities of capital (for raw materials and infrastructure) and assuring a high production output.[70]

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.[71] Nef held that in England brewing must have been one of the principal motors behind the coal industry before the industrial revolution.[72] Similar assertions could be made for the Southern Low Countries.[73] 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 Schoonbeke actively invested in the extraction of peat and coal, by acquiring shares in the mining industry or starting a mining company themselves.[74] By the beginning of the seventeenth century, the shift to coal among brewers in the Southern Low Countries was complete.[75] Also in early modern Holland brewers were notable coal consumers. More than any other industry, Dutch brewers petitioned for permission to use coal. In the first decades of the seventeenth century, brewers in Delft, Dordrecht, Rotterdam and Haarlem asked for authorization to stoke coal as an alternative to peat in the winter when frozen canals often kept sufficient peat supplies from reaching the towns.[76] Because of their fuel costs (among other costs for raw materials

[66]Nef, *The Rise of the British Coal Industry*, 215–16.

[67]Deseijn, 'Zoutproductie in Gent', 20–2.

[68]Deseijn, *Bouwen voor de industrie*, 227.

[69]R.L. Stein, *The French Sugar Business in the Eighteenth Century* (Baton Rouge, 1988), 132.

[70]Deseijn, 'Zoutproductie in Gent', 22–7.

[71]Soly, 'De economische betekenis', 109; Unger, *A History of Brewing in Holland*, 100–3.

[72]Nef, *The Rise of the British Coal Industry*, 213.

[73]And these have been made in Soly, 'De economische betekenis', for instance.

[74]J. Lejeune, *La formation du capitalisme moderne dans la principauté de Liège au XVIe siècle* (Liège, 1939), 343–5.

[75]M.-J. Eykens, 'De brouwindustrie te Antwerpen 1585–1700', University of Ghent MA thesis, 1972.

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

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such as those for hops and grains), breweries usually had the necessary capital available to fall back on the expensive – but more constant – flow of coal supplies. In the Northern Low Countries, urban governments 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 Dutch breweries (and distilleries), like those in Flanders and Brabant, by the end of the seventeenth century.[77]

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 large quantities of bottles in the eighteenth century.[78] The technique for bottle making was based on English technology which involved the use of coal-customized furnaces.[79] 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 and centralized production of cheap glasswork, but it also had the desired effect of darkening the glass of the bottles.[80] Unlike 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 specialization in bottle making in the Low Countries' glassworks – 'to English fashion' – thus involved a broader shift to a new production technique, away from high-skilled job production towards capital- and energy-intensive mass production.[81] And this tendency towards serially 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 earlier 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 production and metalworking were not uncommon.[82] Like the glass oven, the steam engine was an English invention that was specifically designed to be fuelled with coal. For this reason, modern machine technology entered the Dutch economy only slowly – as we have already seen above.[83] Moreover, for their mechanical energy, the Dutch traditionally – and famously so – relied on windmills, as well as watermills and horse mills.[84] It has been argued – most recently by Herman Kaptein – that investments in mechanization through wind

[77] *Ibid.*, 101–2.

[78] 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.

[79] E.S. Godfrey, *The Development of English Glassmaking, 1560–1640* (Chapel Hill, 1975).

[80] 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.

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

[82] Smit, 'De introductie van de stoomkracht', 529; SAG, Series K, Handel en nijverheid, no. 96.

[83] H.W. Lintsen, 'Een land zonder stoom', in *idem* (ed.), *Geschiedenis van de Techniek in Nederland: de wording van een moderne samenleving, 1800–1890*, 6 vols. (Zutphen, 1992–95), vol. VI, 51–63.

[84] K. 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.

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(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.[85] In the Leiden textile industry, for example, windmills, watermills 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 from investing in steam technology before the middle of the nineteenth century.[86] 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 long continued to be 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.[87] Likewise, the Leiden textile industry had known larger manufactories since the seventeenth century.[88] In the first steps towards factory production, the concentration of proletarianized labour into a centralized system preceded the introduction of steam machinery.[89] Furthermore, in those sectors where machine technology was installed, traditional and modern forms of mechanization had long co-existed. Previous research on the industrial use of watermills in England has shown 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.[90] This co-existence of old and new machine technology is evident from the 1806 will of the Leiden cloth producer Jan van Heukelom, whose son would later, in 1816, introduce the first steam engine in the Dutch textile industry. Among the equipment in his factory was mentioned a horse mill, a textile press and several (man-operated) spinning jennies 'designed after the English mechanical practice'.[91] Also in Ghent the mechanization process followed a hybrid pattern. The company of Valentijn van Loo – an early 'textile boss' in Ghent – owned a 'machine à feu avec seize chevaux système anglais et construction anglaise', but also a 'machine à tisser' and a 'machine à filer', which were presumably hand-driven, as well as a 'moulin en bois', as is recorded in the probate inventory of his daughter who died in 1831.[92] In the end, steam technology was favoured over traditional sources of power since it was less dependent on the ebbs and flows of nature and could be located more easily in cities where labour was more freely available.[93]

85 H. Kaptein, *Nijverheid op windkracht: energietransities in Nederland, 1500–1900* (Hilversum, 2017).

86 H. Lintsen, 'Stoom als symbool van de industriële revolutie', *Jaarboek voor de Geschiedenis van Bedrijf en Techniek*, 5 (1988), 337–53.

87 Coppejans-Desmedt, *De Gentse textielnijverheid*, 451–4.

88 Posthumus, *De geschiedenis van de Leidsche lakenindustrie.*

89 T.M. Safley and L.N. Rosenband (eds.), *The Workplace before the Factory: Artisans and Proletarians, 1500–1800* (Ithaca, 1993); P. Kriedte, *Peasants, Landlords and Merchant Capitalists: Europe and the World Economy, 1500–1800* (Leamington Spa, 1983).

90 J.W. Kanefsky, 'The diffusion of power technology in British history, 1760–1870', University of Exeter Ph.D. thesis, 1979.

91 RAL, Old notary archives, no. CXCI/2634.

92 State Archives Ghent, New notary archives, no. NOT639/62.

93 Malm, *Fossil Capital.*

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.[94] 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'.[95] 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 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.[96] 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 1834–64, which in all other cases heavily favoured the consumption of domestically produced peat by levying much heavier taxes on imported fuel.[97] 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 towards peat as well.

It can be assumed that except for baking, linen bleaching and cloth dyeing most industries considered in this article were coal burning. 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 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) took place. 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 had represented a marginal but not insignificant part of the energy mix since the seventeenth century. 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, in short, was incorporated in the energy metabolism of the Low Countries' industrial city – in the South as well as in the North.

[94]J. Boessenkool, 'De eerste stoommachine in de Twentse textielindustrie', *Textielhistorische Bijdragen*, 4 (1963), 68.

[95]RAL, City Archives of Leiden III, 1816–1929, no. 4567.

[96]RAL, Archives of J.J. Krantz & Zoon te Leiden, 1797–1970, no. 692.

[97]J. Teijl, 'Brandstofaccijns en nijverheid in Nederland gedurende de periode, 1834–1864', in J. van Herwaarden (ed.), *Lof der historie: opstellen over geschiedenis en maatschappij* (Rotterdam, 1973), 155–83.

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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 for the industrial coal consumption. Total coal consumption levels are derived from Ryckbosch and Saelens, 'Fuelling the urban economy'.

Conclusions

This comparative study has tried to offer a 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 less essential for industrial development than is often maintained in the historiography on the 'energy revolution'. While its better availability in the Southern Low Countries may in the first instance have coincided with the region's earlier and stronger tendency towards industrialization as compared to the North, coal does not appear to have been the *ultimate* condition that triggered the industrial revolution. Relative to other consumers – coming mainly from the household economy – industry was not a major consumer of energy. Bigger energy transitions were therefore dependent on the choices of ordinary homemakers rather than those of industrial producers. However, before the large-scale adoption of coal by the majority of energy users who were largely persuaded by shifting relative prices, specific industries had already followed earlier coal-burning trajectories, not only in Ghent but also in Leiden – even if coal did not provide the cheapest price for energy. 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, just as in the Southern Low Countries. The industrial demand for coal in the end had a stronger effect than the supply of coal per se.

In this respect, the history of energy was not 'the secret history of industrialisation', as Rolf Peter Sieferle claimed.[98] Rather, the opposite was true. Perhaps, indeed, explanations for the intimate (or 'metabolic') relationship between coal and industrialization should be found in the internal organization of the involved industries themselves. Why did these industries turn to coal? More research is obviously needed, but there is an interesting feature that binds together all the coal-burning industries. Textile production, glass making, sugar and salt refinery, soap boiling and brewing – all of these industries were 'new industries', the production process of which was more capital-oriented compared to traditional guild-based industry. For industrial capitalists, coal had the advantage, not only of producing higher energy levels, but also – and more importantly – of offering more compact storage and reduced handling time; consequently, enabling the centralization of the

[98]R.P. Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution* (Cambridge, 2001), 137.

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labour needed to service a fire or to operate a machine. Less bound to the constraints of time and space, coal-fuelled technology enabled the centralization of the production process in which labour and capital (the latter in the form of energy) were integrated into a single enterprise.[99] The introduction of coal technology, in other words, could not have happened without the willingness of entrepreneurs to invest in a centralized production system and hence without the availability of industrial capital. And this centralization process was already well under way before the diffusion of steam – through traditional wind and water technology in the textile sector and through heat-intensive developments among glass makers, refiners, soap boilers and brewers.

With regard to labour and capital concentrations in manufacture, there were important differences between the Northern and Southern Low Countries. While in the Northern Low Countries capital was mostly concentrated in trade and finance rather than industry, entrepreneurs in the Southern Low Countries started to actively interfere during the early modern period in the production process and gradually acquired the necessary capital to do so.[100] Maybe this difference between 'mercantile capital' in the North and 'industrial capital' in the South was exactly the reason why in Holland the industrialization process was generally much less pronounced, rather than being the result of poor coal endowments. In industry where sufficient capital was at hand – such as in Leiden, where, as an exception to the Dutch rule, important parts of the urban industry had already been centralized into manufactory production since the seventeenth century – investments in coal technology would eventually follow. Less the result of the location of energy stocks, 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.[101]

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0963926822000645.

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[99]Malm, *Fossil Capital*.

[100]C. Lis and H. 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 (1997), 211–42.

[101]Wrigley, *Continuity, Chance and Change*, 115.

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