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Ryckbosch, Wouter; Saelens, Wout

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Fuelling the urban economy: a comparative study of energy in the Low Countries, 1600-1850

Wouter Ryckbosch & Wout Saelens

What was the role of energy in the creation of modern economies and the fuelling of modern economic growth? In the great divergence debate and the wider historiography on the Industrial Revolution, the transition to fossil energy carriers often plays a central role.[1] At least since the 1980s energy has taken centre stage in the historiography of the British industrial revolution. Expanding on older work by John Nef, E.A. Wrigley in particular developed a highly influential model on the relationship between energy, industrialisation and intensive economic growth.[2] He argued that transition from an *organic* to a *mineral economy* was an essential precondition for industrialisation and modern economic growth. In order for the English economy to escape Malthusian constraints and to follow a 'path of sustained growth', it required vast amounts of kinetic energy to be unleashed by new energy carriers – fossil fuels in particular.[3] An organic economy, characterised by low levels of energy consumption derived from energy *flows* generated by photosynthesis, would not be able to muster sufficient energy levels to fuel the widespread substitution of capital for labour which characterised the industrial revolution. A mineral economy, on the other hand, draws on pre-existing *stocks* of fossilised energy such as coal, oil and gas, which allow it to break through the traditional constraints on

[1] For instance, see Pomeranz, *The great divergence*; Allen, *The British industrial revolution*; Malanima, 'The limiting factor'. See Vries, 'Are coal and colonies' and Clark and Jacks, 'Coal and the industrial revolution' for a contrasting view. A long-term overview of the importance of energy in history is in Cipolla, *The economic history*; Kander, Malanima and Warde, *Power to the people*; Smil, *Energy in world history*; Smil, *Energy and civilization*; Burke III, 'The big story'; Fouquet, *Heat, power and light*; Fouquet and Pearson, 'A thousand years of energy use'; Crosby, *Children of the sun*.

[2] Nef, *The rise of the British coal industry*; Wrigley, *Continuity, chance and change.*

[3] Wrigley, *Energy and the English industrial revolution*; Idem, *The path to sustained growth*.

the availability of both land and labour.[4] This influx of energy was thus closely associated with the growth of labour and land productivity, and, hence, with the onset of modern economic growth. Detailed empirical research by John Hatcher and Paul Warde has shown that an early transition to a coal-based economy – prior to the seventeenth century – already set England and Wales apart from the rest of Europe well before industrialisation occurred in the eighteenth century.[5] Robert C. Allen has incorporated this early transition to coal as an important explanatory element in his own 'high wages, cheap energy' model of the British industrial revolution.[6]

Despite the critical importance of this debate – not only for providing a better understanding of the primary causes of modern economic growth, but also for gaining an insight into the connections between economic growth and energy consumption – comparative work on energy transitions during the early industrial revolution is scarce. Empirical studies on industrialising regions that might help us better to understand or qualify the English *Sonderweg* in terms of energy are almost non-existent.[7] In recent years a group of historians across Europe has begun to address this challenge by producing high-quality estimates of historical changes in energy provisioning for different regions across the world. However, apart from a handful of exceptions, most recent work is concerned with energy transitions during the second industrial revolution, or in countries that industrialised relatively late, such as Sweden,

[4] Wrigley, *The path to sustained growth*, pp. 17-18.

[5] Hatcher, *The history of the British coal industry*; Warde, *Energy consumption in England and Wales.*

[6] Allen, *The British industrial revolution*, p. 80 ff.

[7] This in contrast to broader comparisons of 'access to fossil fuels' in different regions, as in the great divergence literature: see Pomeranz, *The great divergence*, p. 211 ff.; Parthasarathi, *Why Europe grew rich and Asia did not*, pp. 154-68, or, within Europe itself, Fernihough and O'Rourke, 'Coal and the European industrial revolution'.

Italy, Portugal, Spain or the Netherlands.[8] In order to understand earlier processes of energy transition and industrialisation comparable to the English experience, it is necessary to go back further in time and to study other regions.

In a recent contribution to the debate Paolo Malanima has compared aggregate levels of energy consumption in Italy and England between the sixteenth and twentieth centuries. Malanima argues that the 'little divergence' in energy consumption per capita between the two regions, caused by the presence and use of coal in England, helped to ease the pressure on land in England during the seventeenth and eighteenth centuries. However, in order for England to be able to achieve *intensive* economic growth, coal had to be used as a substitute not for land but for labour – which began to happen on a significant scale only from the 1830s onwards.[9] Malanima suggests that this second transition did not follow automatically from the first, but rather that it was contingent upon scientific development, institutions and social structure. On the other hand, it is clear that Italy, where coal was of negligible importance, benefited from neither the land-augmenting, nor the labour-augmenting effects of coal, and was thus stuck on a path to *extensive* economic growth.[10] Malanima's study thus confirms that coal was probably a necessary – but by no means a sufficient – condition for early industrialisation, while also

[8] For instance, see Malanima, *Energy consumption in Italy*; Warde, *Energy consumption in England and Wales*; Kander, 'Economic growth'; Henriques, *Energy consumption in Portugal*; Henriques, 'Energy transitions'; Gales et al., 'North versus South'; Hölsgens, 'Energy transitions'; Nielsen, Warde and Kander, 'East versus West'; Nielsen, 'Coal, commerce and communism'; Unger and Thistle, *Energy consumption in Canada*; Sandwell (ed.), *Powering up Canada*; Jones, *Routes of power*; Henriques and Sharp, 'The Danish'.

[9] Malanima, 'Energy consumption in England and Italy'.

[10] Elsewhere, Malanima has pointed to the close link between energy consumption and economic crisis and growth across early modern Europe: 'Energy crisis and growth'; 'The energy basis for early modern growth'.

showing that the deep roots of England's energy transition do not necessarily imply equally deep roots for England's economic exceptionalism.[11]

If a comparison between Italy and England is instructive for its telling contrast between a coal-poor and stagnant economy and a coal-rich and growing one, the question remains whether only 'two pathways toward energy transition' were possible.[12] Both Malanima and Wrigley have argued that in the comparison between Italy and England the latter was 'the odd one out', and that the Italian case was 'the normal one', representative of much wider experience.[13] But how exceptional was England, and in what respects? If we are to disentangle the varied effects of coal on economic growth and industrialisation, as well as to identify the factors upon which those were contingent, a different kind of comparison may well be in order. The present study aims to offer a new empirical contribution to the literature on early energy transitions by presenting the Low Countries from the seventeenth to the nineteenth centuries as a case for comparison.

Studying the Low Countries offers the potential to challenge some of the notions that currently shape the debate on the role of energy in the industrial revolution. Both Wrigley and Allen, following a pioneering study on Dutch energy attainability in the Golden Age by J.W. De Zeeuw, have pointed out that the Dutch Republic (the present-day Netherlands) was probably the only exception to the generally low and stagnant levels of energy consumption

[11] This would re-emphasise the 'chance' factor in Wrigley's *Continuity, chance and change*, as well as Pomeranz' interpretation of England as a 'fortunate freak': *The great divergence*, p. 207.

[12] The quotation refers to the subtitle of Malanima, 'Energy consumption in England and Italy'.

[13] Malanima, 'Energy consumption in England and Italy'; Wrigley, *Energy and the English industrial revolution*, p. 95.

across early modern continental Europe.[14] Because of the availability of peat in the Netherlands it was seen as an exceptional high-energy economy, even though it remained locked within the traditional constraints of organic economies.[15] Despite this recognition of its supposed exceptionality, the early modern energy transition of the Dutch Republic has not yet been integrated into the dominant models of the relationship between energy and economy. This stands in contrast to the position of the Southern Low Countries (present-day Belgium), where the use of peat was rarer during the early modern period,[16] but which is frequently invoked as the first industrialising region on the continent as a result of its access to cheap coal.[17] In fact, the early industrialisation of Belgium is often referred to in support of the hypothesis that cheap energy was responsible for British industrialisation: 'The only place outside of Britain with a similarly high ratio of labour to energy costs was probably the coal mining district around Liège and Mons in present-day Belgium.'[18] Given the contrasting but equally exceptional trajectories of energy transitions in the Northern and Southern Low Countries over the course of the seventeenth to nineteenth centuries, the region is an ideal case in which to study the relationship between energy and economic development.

The design of this study is comparative in nature. Following earlier literature on the importance of regional and local variation and diversity in industrialisation,[19] we offer a comparative perspective on two cities with contrasting developments in economy and energy

[14] Wrigley, *Continuity, chance and change*, pp. 57-60; Wrigley, *Energy and the English industrial revolution*, pp. 216-25; Allen, *The British industrial revolution*, pp. 98-104.

[15] De Zeeuw, 'Peat'; Unger, 'Energy sources'; Gerding, *Vier eeuwen turfwinning*; Van Zanden, 'Werd de Gouden Eeuw'; Van der Woude, 'Sources of energy'.

[16] Soens and Thoen, 'Mais où sont les tourbières'.

[17] Hasquin, *Une mutation*; Van der Wee, 'The industrial revolution in Belgium'; Mokyr, *Industrialization*.

[18] Allen, *British industrial revolution*, p. 103.

[19] Pollard, 'Industrialization'; O'Brien, 'Do we have'.

between the seventeenth and nineteenth centuries. We aim to explore how energy regimes varied across time and space, and how these variations ultimately led to divergent economic paths of development by choosing two cities in different political entities and largely divergent economic regions: Leiden, in the Northern Low Countries, and Ghent, in the Southern Low Countries. We have collected new data on the chronology, nature and scope of energy consumption, reaching back to the earliest energy transitions in early modern Europe. After presenting the methodology and sources, we will put them to work in addressing the central question: what was the importance of energy in fuelling the urban economy? Our results for the Low Countries indicate a different and reduced role for energy than in some of the models which currently dominate the literature.

Methodology and sources

To assess the role of energy transitions in economic development in the Low Countries we will take a different approach to most of the existing literature. First, the scale of analysis is limited to the urban level. As urban economies still formed an important locus for industrial production, while being more acutely confronted with problems of energy supply than rural areas, cities can serve as the canaries in the coal mine for detecting changes in energy consumption.[20] Moreover, since much of the urban energy supply had to be procured beyond the city walls, the import of energy carriers also happens to offer historians interesting opportunities for data collection.

[20] Important studies that exploit such an urban perspective to the fullest are, for instance, Mosley, *The chimney*; Cavert, *The smoke*.

A second way in which this study offers a new empirical approach is in its reliance on a large collection of (almost) yearly available consumption data. It builds on newly gathered and previously unpublished archival data. The existing pre-industrial estimates of energy consumption are based on a tremendous effort to gather data on all dimensions of agricultural and non-agricultural energy sources, but they must necessarily also rely heavily on assumptions and extrapolations. Malanima's estimates of early modern energy consumption are derived from comparisons between price series, demographic data and per-capita estimations of fuel needs, rather than direct consumption data.[21] Warde's data for England are thoroughly empirical, adopting export and production figures from various coalfields provided by Hatcher and Flinn. Yet for the pre-1700 period – the most critical period in the British energy transition – these figures are based on only two benchmarks, which Warde has augmented with minimum estimates from available production sites and maximum estimates following more qualitative indicators of production and consumption in order to extrapolate for the whole of England and Wales.[22] Choosing only small areas – i.e. cities – as our units of analysis here makes it considerably easier to produce almost yearly and more direct estimates of energy inputs. Although this inevitably reduces the representativity of the results, it improves the quality and fine-grained nature of our data.

The aim of this article is to study the relationship between energy transitions and economic change. An energy transition can be defined as a structural change in the energy system: in the type of energy sources exploited, the quantities produced and consumed or the efficiency with which they were used. In this study the focus is on the *amounts* of energy produced for human use and consumption, as well as on the *types* of energy sources or carriers

[21] Malanima, *Pre-modern European economy*, pp. 56-60; Malanima, *Energia e crescita*, p. 47 ff. Compare with: Kander, 'Economic growth', pp. 22-36.

[22] Warde, *Energy consumption in England and Wales*, pp. 59-60.

from which they are derived. The first objective is to estimate the total size of primary energy inputs in the two urban societies under scrutiny. Our definition of primary energy inputs here is limited in three ways: 1) we measure only the energy sources that come with an exploitation cost (i.e. free solar energy, which might warm a house without artificial heating during the summer, is not included), 2) we measure only the total energy inputs in the economy, not the levels of 'useful energy' (i.e. the energy that is transferred into work or heat, meaning that the 'wasted' energy lost through the chimney when burning wood in a fireplace or the efficiency losses of a steam engine are also included)[23], and 3) we measure all primary energy sources consumed within the confines of the cities of Ghent and Leiden: this largely excludes the energy required for the transport of goods outside those cities or for the production of goods elsewhere.

Most long-term histories of energy rely on a supply-side approach to study the consumption of energy. This means that estimates are often based on the potential supply capacity of available energy sources, rather than on evidence of actual consumption: firewood consumption is derived from the total acreage of extant woodland; coal consumption is based on mining and import figures; wind and water energy are approximated through the number of mills in existence and/or operation; animal power is based on the number of cattle, etc.[24]

[23] On 'useful energy' and other concepts and definitions in energy history see Malanima, 'Energy consumption in England and Italy', pp. 87-90; Kander, Malanima and Warde, *Power to the people*, pp. 22-23; Fouquet, *Heat, power and light*, pp. 8-9; Smil, *Energy and civilization*, pp. 8-17.

[24] The first national statistics appear only after 1800. Pre-industrial data are therefore usually derived from estimates of the supply rather than the demand side: Malanima, *Pre-modern European economy*, pp. 49-94; Warde, *Energy consumption in England and Wales*, pp. 21-63; De Zeeuw, 'Peat'; Unger, 'Energy sources'; Sneller, *Geschiedenis van den steenkolenhandel*, pp. 92-96; Nef, *The rise of the British coal industry*, pp. 19-77; Hatcher, *The history of the British coal industry*, pp. 483-507; Flinn, *The history of the British coal industry*, pp.

Although our methodology is indebted to this approach, the use of urban excise taxes allows us to move closer to 'actual energy consumption' than to 'potential energy production'. Excise taxes were usually levied on the import or sale of specific goods within the city walls, and were introduced in most cities of the Low Countries during the late Middle Ages.[25] Between the sixteenth and eighteenth centuries several provincial governments across the Low Countries also introduced excise taxes on the consumption and import of basic commodities.[26] Even after the introduction of a new financial and fiscal system following the French occupation in the late eighteenth and early nineteenth centuries, cities in Belgium and the Netherlands continued to levy similar import and consumption taxes until the 1860s.[27] Since excise taxes were usually levied on the volume or weight of goods sold in or imported into the city, the revenue they produced can be used as a proxy for the consumption of that particular good. Especially for studies of food consumption these sources have previously been mobilised to estimate per capita quantities of food and drink consumed.[28]

Based on the excise revenues on fuels for Ghent and Leiden for the seventeenth, eighteenth and nineteenth centuries, together with sources that allow for the estimation of

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23-35. Exceptions that use a demand-side approach in the reconstruction of pre-industrial energy consumption are Van Zanden, 'Werd de Gouden Eeuw'; Vandenbroeke, 'Zuinig stoken', p. 105; and Van der Woude, 'Sources of energy' which used excise taxes.

[25] See for a general overview, including a chapter on Antwerp, Ucendo and Limberger, *Taxation and debt*, and, more specifically for the late medieval origins of urban excise taxes in the Low Countries, Boone, 'Stedelijke fiscaliteit'; Marsilje, *Het financiële beleid*.

[26] Janssens, 'Taxation'; Fritschy, *Public Finance of the Dutch Republic.*

[27] Segers, 'Een omstreden verbruiksbelasting'; Bigwood, 'Les impôts généraux'; Teijl, 'Brandstofaccijns en nijverheid'; Gerding, 'Turfaccijns en turfproductie'; Engels, *De belastingen en de geldmiddelen*.

[28] For example, see Vandenbroeke, 'L'alimentation à Gand'; Segers, 'Oysters and rye bread'; Aerts, 'Het hoofdelijk bierverbruik'.

energy inputs produced by wind, water and animal fodder, we can reconstruct the consumption of energy in the two cities in the long run. We include five different types of energy carriers: food for human beings; fodder for working animals; wind; water; and fuels: firewood, charcoal, peat and coal. Revenues from excises on grain, beer and meat form the basis of our estimates of energy from human labour (food).[29] The energy produced by animal labour is estimated on the basis of horse taxes, which allow for the reconstruction of the amount of fodder needed to feed all horses used for transport and animal work that grazed within the confines of the city.[30] Our estimates of the energy produced by wind and water are constructed on the basis of the excise on grinding, or the 'mill penny', which was a tax on the gristmills within the jurisdiction of the city.[31] For mills other than gristmills, the estimate is based on mill databases compiled by amateur historians who used census data and the cartographic record.[32] Fuel excises on

[29] Ghent: City Archives Ghent (hereafter SAG), series 498 (grain excise); SAG, series 501 (meat excise); SAG, series 522 (beer excise). These excises are discussed in Van Daele, 'Proeve', pp. 19-30, pp. 33-59, pp. 71-79. SAG, series L65 (municipal excise taxes). The nineteenth-century grain, meat and beer excises are discussed in Vandenbroeke, 'Voedingstoestanden te Gent'. Leiden: City Archives Leiden (hereafter 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.

[30] These taxes were not levied on horses that provided transport outside the city. Ghent: SAG, series 62 (bestiaalgeld); SAG, Series L13/2 (horse tax). Leiden: National Archives (hereafter NA), Financie van Holland, nos. 826-828.

[31] Ghent: SAG, series 499 (milling excise). Discussed in Van Daele, 'Proeve', pp. 15-8. 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.

[32] Ghent: Belgian mill database 'Verdwenen Molens': https://www.molenechos.org/index.php. Leiden: Dutch mill database 'Verdwenen Molens': https://www.molendatabase.org/.

firewood, charcoal[33] and coal for Ghent and on firewood, peat and coal for Leiden complete the picture of the energy regimes in the two towns – even though some imputations and extrapolations were necessary when the municipal accounts could not provide sufficient detail for each of the energy carriers.[34]

The use of urban excise taxes has its advantages in terms of chronological scope and data quality, but brings with it a number of methodological issues. Most importantly, some energy carriers were not taxed and are thus missing from the fiscal record. Peat was left untaxed in Ghent, while the *kolenexcijs* in Leiden grouped together both charcoal and peat coal, along with coal (*steenkool*). In those cases where less commonly consumed fuel types remain excluded from the excise revenues, we have relied on a secondary indication: the relative importance of each fuel type in the costs of heating municipal buildings recorded in the city accounts.[35] These sources reveal that coal in Leiden and peat in Ghent were hardly burned in the cities' public buildings. This is also confirmed by probate inventory evidence which traced the material culture related to domestic heating and cooking (coal scuttles, ranges, peat tuns, andirons for supporting wood logs, etc.) for both cities.[36]

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[33] In the case of Ghent, charcoal – a secondary product of wood – was included, since its consumption was recorded separately from the firewood excise and it, thus, from the perspective of the energy consumer, served as a primary source of energy. On the distinction between primary and secondary energy carriers see Kander, Malanima and Warde, *Power to the people*, pp. 20-21.

[34] Ghent: SAG, series 400 (city accounts), nos. 158-256; SAG, series 515 (coal excise); series 516 (charcoal excise); series 518 (firewood excise) (discussed in Van Daele, 'Proeve', pp. 129-45). SAG, series L65 (municipal excise taxes). 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.

[35] GAL, city archives II, blaffaards van de tresorier ordinaris, nos. 9722-10095.

[36] Saelens, 'The comforts of energy'.

A second challenge, common to all historical studies of energy consumption, is the problem of conversion. The fiscal units – usually expressed per volume or weight of fuel – have to be converted to standardised (metric) units of measurement first, and then the metric quantities need to be converted into the amounts of energy they were capable of producing given the technological context of the time. The revenue of 615 pounds, 3 shillings and 8 pence for the coal excise in Ghent in 1789-1790, which corresponded to a total number of 295,288 sacks of coal, thus needs to be converted into energy quantities in order for one to arrive at a meaningful comparison with the 'tuns of peat' sold in Leiden in that same year. Assessing the energy value of each fuel type relies on secondary literature, and inherently implies a level of uncertainty and reduction in variety. For instance, expensive logs of oak produced a higher return in terms of heating value than a cheap bundle of brushwood, depending also on the season, moisture content and external circumstances in which each wood type was burned. Coal also came in several varieties and could be either 'fat' or 'meagre'– the former was of a higher quality than the latter.[37] Dutch peat could be 'high' or 'low peat,' depending on where it was cut (in the raised bogs of the North or the low-lying fens of Holland and Utrecht).[38] As the sources often contain insufficient detail for one to be able to distinguish between varieties, we rely instead on a fixed conversion value per energy carrier.

The data conversions used and the motivations behind them are specified in Appendix A. The conversion choices were based on the most reliable sources and estimates available to the best of our knowledge, but it is not unlikely that in the future some of these can, and hopefully will, be improved. However, we believe that for the purpose of our long-term, comparative study within a confined geographical area, the conversion factors used are sufficiently reliable. The conversion issue becomes more pressing when one compares across

[37] Gales, *Delven en slepen*, pp. 29-38.

[38] De Zeeuw, 'Peat', p. 29.

different studies and larger areas. Our estimation of the energy produced by peat is notably higher than the energy value used by Allen. Since our study is not primarily focused on comparing the results with Allen's, we have opted to rely on the most reliable local and contemporary conversion rates available rather than on full comparability.[39]

In order to reconstruct energy transitions in the long run and to assess their relationship with economic development, this study uses a comparative research design.[40] The research units are two cities situated approximately 135 km apart, with a comparable economic function as industrial centres and a similar position within the urban systems in which they were situated.[41] The city of Ghent was located in the County of Flanders, in the Austrian Netherlands, and was renowned mainly as a textile production centre established during the later Middle Ages.[42] After a period of relative decline, the expansion of the industrial (and increasingly mechanised) production of linen and cotton textiles in the eighteenth and nineteenth centuries turned Ghent into one of the first industrialising cities on the continent of Europe.[43] The city of Leiden was situated in the County of Holland, one of the provinces in the Dutch Republic. Like Ghent's its most important economic activity was the production of textiles for export, which reached its highest prominence during the seventeenth century.[44]

Despite the similarities, there were also noteworthy elements of contrast between the two case studies selected here. At the political level, after the Dutch Revolt Ghent remained

[39] The conversion factor from peat is based on local geoarchaeologial research: Augustyn, *Zeespiegelrijzing*, p. 492; Leenders, *Verdwenen venen*, p. 263.

[40] Mahoney and Rueschmeyer, *Comparative historical analysis*.

[41] Based on the appendices in De Vries, *European urbanization* and Bairoch, Batou and Chèvre, *La population*.

[42] Nicholas, *The metamorphosis*, pp. 135-54; Boone, 'L'industrie textile à Gand'; Munro, 'Medieval woollens II'.

[43] Coppejans-Desmedt, 'De Gentse textielnijverheid'.

[44] Posthumus, *De geschiedenis*.

part of the catholic Habsburg Empire, where it maintained a considerable degree of autonomy in local affairs until the end of the eighteenth century, but had little influence on national or international policy-making in Brussels, Madrid and Vienna.[45] Leiden meanwhile became part of the Dutch Republic at the end of the sixteenth century, when its urban political elites had a say not only in local affairs but, through the Estates of Holland and the Estates General, also in national and international governance.[46]

In terms of industry, too, the two cities took different paths from the sixteenth century onwards. Whereas woollen cloth production had rapidly lost its position to linens (and, in the nineteenth century, to cotton as well) in early modern Ghent, Leiden remained focused on the production of (lighter) woollens until the nineteenth century. At that time Leiden was still the most important textile centre in the Netherlands (together with Tilburg), and it was the first to introduce steam engines into Dutch textile production in 1816, but never became a mechanised industrial centre like Ghent.[47]

[Figure 1]

From the beginning of the seventeenth until the middle of the eighteenth centuries the population size of both towns was similar – ranging between 40,000 and 50,000 inhabitants (Figure 1). After a period of relative demographic stability, the population of Leiden experienced a prolonged decline from the last quarter of the seventeenth century until the second quarter of the nineteenth. This roughly corresponds to the relative economic decline

[45] Lenders, *Gent, een stad tussen traditie en verlichting*.

[46] Prak, *Gezeten burgers*.

[47] Van Zanden and Van Riel, *The strictures of inheritance*, pp. 121-44; Smit, 'De introductie'.

that beset Holland during this period.[48] Beginning around the middle of the eighteenth century the demographic fate of the two towns diverged. As Leiden's population continued to decline, the number of inhabitants in Ghent climbed from ca. 45,000 in 1750 to 55,000 in 1800 and reached more than 100,000 by 1850. Only from the 1830s onwards did the population of Leiden again experience growth, even though it remained more modest than in Ghent. By 1860 – the end date of our study – Ghent had become more than three times as large as Leiden. Although their starting positions in terms of economic and demographic circumstances were highly comparable at the beginning of this study, they had diverged significantly by the end of this period. What was the role of energy in this divergence between the Northern and Southern Low Countries?

The energy regimes in Ghent and Leiden compared

Despite the geographical proximity as well as economic similarity of Ghent and Leiden, the two cities differed from one another in the way they procured their energy. Figure 2 shows the importance of fossil fuels in the total energy mix in Leiden and Ghent. We interpret both coal *and* peat as 'fossil fuels' – or 'proto-fossil' in the case of peat – following Smil's definition of 'limited and nonrenewable (or not renewable on a historical time scale) deposits of a young fossil fuel.'[49] Although often regarded as a more traditional fuel than coal, peat also provides energy in the way of a stock, rather than a flow, of energy. Therefore, it has been noted that there are 'close parallels between peat usage in the Netherlands and coal consumption in

[48] The precise chronology and extent of this economic stagnation is debated between De Vries and Van der Woude, *The first modern economy*; and Israel, *The Dutch Republic*.

[49] Smil, *Energy and civilization*, p. 196.

England' during the early modern period.[50] Within the Low Countries itself, however, the differences in the trajectory of fossil fuel dependence were pronounced: Ghent used less fossil fuel in the seventeenth century, but overtook Leiden around the turn of the nineteenth. The level of fossil fuel dependence in Leiden at the beginning of the seventeenth century is remarkable: it stood at above 70 per cent. This figure remained fairly constant far into the nineteenth century.

[Figure 2]

These figures cannot be straightforwardly compared with the available estimates at the national level. Since rural contexts generally enjoyed easier and cheaper access to organic energy carriers, the consumption of fossil fuels was disproportionately concentrated in cities. This is clear when the figures for Leiden are compared with the estimates produced by Ben Gales for the nineteenth-century Netherlands as a whole (Table 1).[51] In 1800 the share of fossil fuels in the Netherlands was ca. 34 per cent and rose to 53 per cent by 1860. Unsurprisingly this is considerably smaller than the 67 per cent and 73 per cent for 1800 and 1860 respectively in our urban data for Leiden alone (Table 2). The results for the city of Leiden are thus not representative of the Northern Low Countries as a whole, although they do indicate that in specific urban contexts the exceptionally early reliance on peat can be traced back to the beginning of the seventeenth century – which ties up well with Charles Cornelisse's findings for the fifteenth and sixteenth centuries.[52] The contrast with most other European regions –

[50] For instance, see Wrigley, *Energy and the English industrial revolution*, p. 221.

[51] Gales et al, 'North versus South', pp. 224-26.

[52] Cornelisse, *Energiemarkten*. See also De Zeeuw, 'Peat'; Unger, 'Energy sources'; Van Zanden, 'Werd de Gouden Eeuw'.

England and Wales excepted – is stark: around 1870 Portugal, Italy, Spain, Sweden and Canada relied for approximately 90 per cent of their energy mix on renewable, non-fossil energy carriers.[53]

To this date no comparable data for the energy mix in nineteenth- or twentieth-century Belgium has been available. Yet, it is clear from data on coal production that Belgium wholeheartedly took the road to a fossilised energy trajectory from the first half of the nineteenth century onwards.[54] The analysis of contemporary household budget surveys has also shown that by the end of the nineteenth century coal had become the single most important fuel for home heating in Belgium.[55] Ghent played a leading role in this wider Belgian pattern. By 1800 the city's reliance on fossil fuels had already arisen to above 60 or 70 per cent (Table 2), which at the time was probably only rarely achieved outside England and Wales. Compared to other regions in Europe Ghent experienced a rapid energy transition during the second half of the eighteenth century. Even within the Southern Low Countries itself, Ghent's trajectory was steep. The port city of Antwerp, situated further down the river Scheldt, switched to coal only after the turn of the nineteenth century, while the capital city of Brussels has long profited from the cheap wood produced in the nearby Sonian Forest.[56] In terms of a pre-industrial, pre-1800 transition to fossil fuels, cities in the Low Countries such as Ghent and Leiden – in both the Northern and Southern parts – clearly much more closely resembled England and Wales than the rest of Europe (or the world).

[53] Henriques, *Energy consumption in Portugal*, appendix I; Gales et al., 'North versus South', appendices 1A and 2A; Unger and Thistle, *Energy consumption in Canada*, appendix I.

[54] Mitchell, *European historical statistics*, pp. 381-91; Vandenbroeke, 'Zuinig stoken'.

[55] Segers, *Economische groei*, pp. 157-60, pp. 548-9.

[56] Braspenning, 'Een warm nest'; Verboven, 'Het bos'.

[Table 1]

[Table 2]

Figures 3 and 4 and Tables 3 and 4 show the estimated energy mix per carrier in Ghent and Leiden from the first half of the seventeenth until the second half of the nineteenth centuries. They confirm the different chronologies of the transition to fossil fuels in Ghent and Leiden, but also highlight important differences in specific energy carriers. While Ghent had a highly diversified energy regime in which fuelwood played an important role until the middle of the eighteenth century, Leiden's energy mix was dominated by peat throughout. Before the rise of coal the dominant fuel in Ghent had been firewood, which accounted for roughly 40 to 60 per cent of total energy consumed. Charcoal added another 5-10 per cent of the total energy requirements. As early as in the fifteenth-century accounts of the urban finances, the 'peat tax' (*turfpacht*) in Ghent included a tax on coal.[57] In the early seventeenth century this tax was renamed the excise on *'luijxsche, smede houillecolen en boscolen'*: a tax on smith coals, coal from Liège and charcoal. From 1643 we can measure precisely how much coal was imported and consumed within the city annually.[58] By the middle of the seventeenth century coal contributed approximately 15 to 20 per cent to the city's energy mix – a share that would remain constant until the 1750s.[59] Even though coal had been available to consumers and urban industries since at least the beginning of the seventeenth century, it was only after 1750 that it rapidly achieved a dominant position in the city's energy mix. A century later coal would account for nearly 95 per cent of total energy consumption.

[57] Boone, *Geld en macht*, pp. 139-40.

[58] SAG, series 400 (city accounts), nos. 158-256. See appendix A for more details.

[59] Compare to the English situation in Warde, *Energy consumption in England and Wales*, pp. 57-61.

[Figure 3]

[Figure 4]

[Table 3]

[Table 4]

As early as in the seventeenth century the role of fuelwood was much more modest in Leiden than in Ghent. Most striking about the Leiden energy mix is the early reliance on peat. At the beginning of the seventeenth century, the consumption of peat accounted for almost three quarters of the city's energy regime. By contrast, the share of coal in Leiden rarely exceeded 10 per cent and reached a maximum of 15 per cent by 1860. Even when the weight of peat began to decrease after c. 1750, this decline was compensated for primarily by a higher consumption of fuelwood rather than coal. Only after 1800 did the share of coal start to increase slowly but it never rose to more than 15 per cent.[60]

The development of energy consumption

Did the different trajectories of the energy mix in Ghent and Leiden also bring about different conditions for the development of a high- (or low-)energy economy in the two cities? Figure 5 shows the total estimated level of energy inputs consumed in the cities of Leiden and Ghent.

[60] Gales et al., 'North versus South', p. 224.

Over the course of the seventeenth and eighteenth centuries the total energy inputs in both cities fluctuated substantially. In Leiden it increased during the seventeenth century and then experienced a protracted decline throughout the long eighteenth, until the first quarter of the nineteenth. Even at the end of the period surveyed here, in the 1850s the total energy input in the Leiden economy did not surpass the highest levels reached in the seventeenth century. The level of total energy consumption was lower in Ghent, until it embarked on a sustained path of growth from the middle of the eighteenth century onwards. By the early decades of the nineteenth century it greatly surpassed Leiden's energy needs, and stood at a level three to four times higher than its pre-nineteenth-century level. This evolution in energy consumption in both cities closely mirrors the adoption of fossil fuels (either peat or coal) in Ghent and Leiden outlined in the previous section. Fossil energy, in other words, allowed the overall level of energy consumption to increase.

[Figure 5]

Since demographic changes affected the two cities differently during this period, the comparison changes when approached in per capita terms. Figure 6 indicates a notable expansion in per capita energy inputs from c. 1750 in Ghent and c. 1830 in Leiden, roughly corresponding to the beginning of the transition to coal in both cities. For the period before the 1750/1830 energy transition the trajectories are less straightforward to interpret, especially in the case of Leiden. Contrary to expectations, energy consumption per capita appears to have declined during the period of industrial expansion in the seventeenth century, whereas it increased during a period of industrial decline in the eighteenth century. The way we measure energy inputs – as described in the Appendix – is more responsive to annual changes in energy inputs from fuels (firewood, coal, peat) than to changes from renewable energy sources (wind

and water). It is therefore possible that our estimations for seventeenth-century Leiden fail to take into account a temporary expansion of wind and/or waterpower during this period of demographic growth, as this has left no traces in the written record. If this is the case, the per capita decline during the seventeenth century is the result of our measurement method, which is more reliable for measuring short-term changes in fuels than in renewable energy carriers.

Despite the decline around the turn of the eighteenth century, the level of per capita energy consumption constantly remained higher in early modern Leiden than in early modern Ghent. According to our estimates, pre-industrial energy consumption per capita fluctuated roughly between 40 and 55 GJ in Leiden, and between 20 and 35 GJ in Ghent. Those figures situate Ghent and Leiden – or Flanders and Holland respectively – within two contrasting types of energy regimes in pre-industrial Europe. Paul Warde has estimated that a per capita energy consumption of c. 40 GJ was attained in England and Wales by the middle of the eighteenth century.[61] Given the different spatial scope of Warde's analysis at the national level, this figure is not easily compared to those for the cities studied here. It can be assumed that in Holland as a whole per capita energy consumption was lower than in the city of Leiden alone. Yet, the high levels of per capita energy inputs reached in seventeenth-century Leiden suggest that the energy regime in Holland operated within a similar scale to that in England and Wales – and perhaps began doing so at an even earlier date. London was the world's largest coal market in the middle of the eighteenth century and consumed almost a ton of coal per head per annum, or about 25 GJ per capita – a figure that can be compared to our estimate for Leiden's peat consumption of c. 30 GJ per capita at the same time.[62] This implies that England's unique and early dependence on coal did not (yet) set it apart from Holland in terms of per capita energy consumption until the middle of the eighteenth century. It seems likely that in seventeenth-

[61] Warde, *Energy consumption in England and Wales*, p. 134.

[62] Cavert, 'Industrial coal consumption', p. 436.

century Holland per capita energy consumption still surpassed English levels of energy consumption, and that it was offset around the mid-eighteenth century only as a result of a long process of decline in Holland and growth in England and Wales. Leiden could thus rely on a uniquely high early modern supply of thermal energy in excess even of that in England and Wales until well into the eighteenth century.

In Southern European countries such as Italy, Portugal or Spain – which were also poor in coal endowments – per capita energy consumption volumes barely exceeded a level of 20 GJ before 1900.[63] The city of Ghent seems to have stood in between the lower per capita energy inputs of pre-industrial Southern Europe and the exceptionally high inputs in Holland, England and Wales. This situation changed from the 1750s onwards, when per capita energy inputs in Ghent set out on a trajectory of growth that was sustained until at least 1860. A similar per capita growth had already taken place in Leiden a century earlier and occurred once more, after a period of stagnation, around the middle of the nineteenth century. The trends in per capita energy consumption suggest that either a peat or a coal regime did not necessarily translate into a divergence between 'traditional' and 'modern' types of fuel trajectories. It is striking that early modern (medium-sized) cities like Leiden and Ghent required large amounts of energy even before economic modernisation set in. During the seventeenth and eighteenth centuries a medium-sized city such as Ghent required more than 1 million gigajoules (GJ) per year, whereas Leiden required well over 2 million GJ in the seventeenth century, and 1.5 million in the eighteenth.

[Figure 6]

[63] Malanima, *Energy consumption in Italy*, pp. 99-101; Henriques, *Energy consumption in Portugal*, p. 135; Gales et al. 'North versus South', pp. 250-251.

A third way in which Ghent and Leiden differed, although to a lesser degree, in their energy regimes was with respect to energy intensity. Energy intensity refers to the amount of energy consumed per unit of output (expressed in monetary terms). It is generally assumed that it tended to increase with industrialisation and economic growth and to decline again during economic maturation and post-industrial growth as a result of the rising importance of services.[64] This inverted U-curve – or 'environmental Kuznets curve' – has been demonstrated in the case of Britain.[65] The early transition to coal in Britain appears to have initiated a first phase of energy-intensive growth, in large part because of the low level of efficiency with which coal was converted into useful energy.[66] In most other European regions, including Italy, Portugal, Spain, Sweden and Czecho-Slovakia, modern growth at later times was accompanied by declining instead of increasing energy intensities, since these late starters could benefit from the adoption of more advanced technologies at an earlier stage.[67]

Given the different chronologies in energy transition and economic modernisation, one might expect a decline in energy intensity to have occurred in the North, while an opposite trend would seem likely in the Southern Low Countries. However, research by Ben Gales has shown that the energy intensity in the Netherlands was in fact growing in the nineteenth century. Based on our longer time series, we are able to go further back in time and to estimate the energy intensity of the Ghent and Leiden economies from the middle of the seventeenth

[64] Goldenberg and Reddy, 'Energy for the developing world'; Bernardini and Galli, 'Dematerialization'; Smil, *Making the modern world*, pp. 143-50.

[65] Kuznets, 'Economic growth'; Ekins, *Economic growth*; Stern, 'The rise and fall'.

[66] Malanima, 'Energy consumption in England and Italy', pp. 93-94.

[67] Malanima, *Energy consumption in Italy*, pp. 72-78; Kander, 'Economic growth', pp. 65-70; Henriques, *Energy consumption in Portugal*, pp. 103-10; Gales et al., 'North vesus South'; Nielsen, Warde and Kander, 'East versus West'.

until the middle of the nineteenth centuries. These estimates of urban economic output measured in constant monetary terms are highly tentative: they have been based on the GDP figures for 'Belgium' and 'Holland'/'the Netherlands' produced by the Maddison Project, adjusted for the difference between the growth rates of population in Ghent and Leiden compared to those in Belgium and Holland respectively, and for the relative positions of both cities within their respective urban hierarchies (more details on the methodology behind this are in appendix B).[68] The results should serve as a rough approximation of the energy intensities in both cities under scrutiny, as we are concerned here only with overall trends. Figure 7 shows that Ghent and Leiden were both more similar to England and Wales than to countries such as Italy, Sweden or Portugal. In both cities, energy intensities increased during the late eighteenth and early nineteenth centuries, thus showing a positive relationship between economic growth and energy consumption consistent with the upward path of the environmental Kuznets curve.

[Figure 7]

The price of energy

The advent of coal is often thought to have made energy cheap. However, the way in which the use of various fuels at different times affected the price of energy in Ghent and Leiden is not necessarily straightforward. Figures 8 and 9 show the evolution of the prices of fuelwood, charcoal, peat and coal in Ghent and Leiden expressed in the grammes of silver needed to

[68] Bolt and Van Zanden, 'The Maddison project', pp. 627-51; Van Zanden and Van Leeuwen, 'Persistent but not consistent'.

produce one GJ. These energy carrier prices were gathered from the accounts of various urban institutions such as hospitals, abbeys and monasteries within the cities of Ghent and Leiden themselves.[69] In Ghent (Figure 8) during the first few decades of the seventeenth century peat and coal were still considerably more expensive than fuelwood, but from 1630 to 1700 the prices of coal and fuelwood converged. Peat seems to have been prohibitively expensive in early modern Ghent as a result of the depletion of the bogs in Northern Flanders.[70] Peat could be imported from Holland, but Dutch export was mainly directed to the towns in Brabant, which were more easily accessible via the Western Scheldt.[71]

Hence, in early modern Ghent the go-to fuel was firewood. Presumably because of diminishing demographic pressure (cf. Figure 1), the price of fuelwood declined during the first half of the eighteenth century. However, from the 1740s onwards its price began increasing quite rapidly, and from 1750 declining coal prices meant that coal became the cheapest energy source available. Despite the huge expansion in the quantities of coal consumed between 1750 and 1860 the price per energy unit remained stable, indicating that the supply was sufficient to match this demand.

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[69] Ghent: Gysen, *Koopkrachtvergelijking*, vol. II, pp. 181-207; Avondts and Scholliers, *Gentse prijzen*, pp. 38-39; SAG, series LXIX (Wenemaerhospitaal), nos. 314-356; SAG, series O (Berg van Barmhartigheid), nos. 31/10-31/14; State Archives Ghent (hereafter RAG), series K42 (Klooster van de Dominicanen), nos. 10-11; RAG, series K75 (Heilige Geesttafels, Sint-Baafs), nos. 1051-1059 and nos. 15211-15220; RAG, series K20 (Nieuwenbosabdij), nos. 231-238 and no. 241; RAG, series K163 (Abdij van Baudelo), no. 824 and nos. 355-357. Leiden (firewood prices are Amsterdam prices; nineteenth-century prices are national prices; all other prices are Leiden prices): Posthumus, *Prijsgeschiedenis*, pp. 45-59, pp. 126-40, pp. 210-16, pp. 286-98, pp. 405-9, p. 477, pp. 502-5, pp. 631-9, pp. 753-64; Dutch national accounts: https://nationalaccounts.niwi.knaw.nl/start.htm.

[70] Soens and Thoen, 'Mais où sont les tourbières'; Jongepier et al. 'The brown gold'.

[71] Cornelisse, *Energiemarkten*, pp. 229-230.

Unsurprisingly, the situation in Leiden was different (Figure 9). There, it was not coal and fuelwood that had closely convergent prices during the seventeenth and eighteenth centuries, but peat and fuelwood. The peat price was usually higher than that of firewood, but not much: the availability of peat at a low price probably served to 'put a lid on wood prices', as coal had done in England.[72] As a result, there was a gradual but sustained increase in the prices of fuelwood and peat from the middle of the seventeenth until the beginning of the nineteenth centuries. For most of the period under consideration coal was a more expensive alternative to fuelwood and peat.

[Figure 8]

[Figure 9]

[Table 5]

The preference for peat over coal in Leiden should not be attributed solely to a lack of access to coal. Certainly, for most of the period studied here coal prices were significantly higher in Leiden than in Ghent as a result of different costs that were involved in transporting the fuel from coalpit to city. Since the Northern Low Countries could not rely on domestic coal and the South could, coal in Holland had to be imported from abroad (England, Belgium and Germany) – which burdened it with extra duties, levied both at home and abroad. However, at the end of the eighteenth century the prices of coal in Ghent and in Leiden were very similar: ca. 3,5 Ag. / GJ. This relatively cheap price for coal should not necessarily be interpreted as a sign of an abundant supply of coal in Leiden, as it might more convincingly signal the low

[72] Allen, *The British industrial revolution*, p. 103.

level of demand for coal. Judging from the energy mix in Leiden, very little coal was purchased, which prevented coal prices from rising. Peat enjoyed a reputation for burning more cleanly than coal, and this was most likely an important argument in the densely populated cities of Holland.[73] When coal consumption did grow in the second half of the nineteenth century, prices rose as well. By this time, the fuel market in Leiden had become better integrated into the European coal market.[74] The price of coal in Leiden had already temporarily declined during the unification of the Netherlands in 1815-1830 as a result of better access to the coal mines in the southern part of Belgium.[75]

The main difference in the energy prices structure between the two cities was thus not that Ghent had access to a cheaper alternative (coal), but that in fact Leiden did (peat). As a result of the abundant supply of peat in Leiden, its energy market continued to have recourse to a cheaper alternative than Ghent's until well into the nineteenth century. Table 5 indicates that throughout the entire period under scrutiny it was not Ghent but Leiden that had access to the cheapest source of energy. The cheaper price of fuel, thanks to the abundance of peat, could explain the higher levels of energy consumption per capita in Leiden during the seventeenth and eighteenth centuries. How the different energy mixes in the two cities related to their economic and industrial trajectories over the course of the eighteenth and nineteenth centuries is a complicated matter – and will be discussed in more detail in the remainder of this article.

Energy and industrial mechanisation: discussion

[73] Unger, 'Energy sources', pp. 233-34.

[74] Ibidem, pp. 241-45.

[75] Van Zanden and Van Riel, *The strictures of inheritance*, pp. 206-10.

We have at the beginning of this article already established the broad comparability of Ghent and Leiden as industrial cities: both were urban centres of regional importance, boasting similar populations around 1700, and having a strong economic focus on the production of textiles destined for export. In discussions of industrialisation in the Low Countries the divergence between the North and South has 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? In his systematic comparative study of industrialisation in the Low Countries Joel Mokyr concluded that the uneven development in this region reflected the reality of a 'duel economy.'[76] Although historians have since come to emphasise more strongly the regional variance of economic development in Europe, the idea of Dutch 'slow industrialisation' remains largely untouched.[77] While many different prime movers of industrialisation have been suggested, access to mineral energy has over the years probably become the most influential explanation of this conundrum. Indeed, Belgium's status as the first industrial nation on the continent has been described as 'based primarily on the coal deposits in the Sambre-Meuse region.' Not only was coal the principal energy source powering the cotton industry and the woollen and iron industries, but the coal mining sector also grew into a major industry in itself, generating 'exceptionally high profits'.[78] The Dutch Republic, on the other hand, is often cited as the prototypical case of an 'advanced organic economy'. It had all the features necessary to become a prosperous and

[76] Mokyr, *Industrialization.*

[77] Van Zanden, 'Industrialization in The Netherlands';

[78] Broadberry, Fremdling and Solar, 'Industry', p. 173. See more generally also: Dhondt and Bruwier. 'The industrial revolution'; Van der Wee, 'The industrial revolution in Belgium'.

modernised economy, but eventually failed to turn its Golden Age into an Age of Steam.[79] The depletion of easily accessible peat bogs and the difficulty in securing coal are often regarded as important factors in this.[80] Even if in terms of Smithian economic growth the Dutch economy in the nineteenth century was certainly no failure, in terms of industrial output Belgium became much more successful than the Netherlands from the end of the eighteenth century onwards.[81]

The cases of Ghent and Leiden as well as their respective textile industries fit this pattern well. The industrial landscape in Ghent was dominated mainly by the production of cloth in the early modern period, as well as cottons in the nineteenth century, together with its having an important role in the finishing and marketing of linen which had been spun and woven in the Flemish countryside.[82] In Leiden woollen cloth had been the main industry since the seventeenth century and would remain dominant well into the nineteenth.[83] As with the energy mix, a clear divergence in economic outcomes can be observed between Ghent and Leiden after 1750. From the late seventeenth century onwards the number of woollen cloth pieces produced and sold on the Leiden market began to decline, from a high point of around 120,000 pieces per year to fewer than 30,000 by 1800. There is no indication of recovery in the Leiden textile industry during the nineteenth century.[84] The number of people working in

[79] De Vries and Van der Woude, *The first modern economy.*

[80] Mokyr, *Industrialization*; Griffiths, *Industrial retardation*.

[81] Van Zanden and Van Riel, *The strictures of inheritance*; Horlings, *The economic development*.

[82] Vandenbroeke, 'Sociale en konjunkturele facetten'; Bastin, 'De Gentse lijnwaadmarkt'; Coppejans-Desmedt, 'De Gentse textielnijverheid'; Dhondt, 'L'industrie cottonière'.

[83] Posthumus, *De geschiedenis*; DuPlessis and Howell, 'Reconsidering'; Lucassen and De Vries, 'Leiden als middelpunt'; Smit, 'De asem van Beëlzebub'; Tjalsma, 'Leidse textielarbeiders'.

[84] Unfortunately the only available figures for the nineteenth century are under-estimations, as cloth to be sold at the market no longer needed to be registered first. Posthumus, *De geschiedenis*, pp. 929-36, pp. 1096-105; Reimeringer, 'De ontwikkeling', pp. 130-1.

the industry fell correspondingly, as it employed approximately 3,200 workers in 1749 compared with 2,715 in 1808.[85]

The experience of prolonged industrial decline in 1750-1850 in Leiden can be contrasted with its rapid growth in Ghent after 1780. By the end of the eighteenth century the cotton printing sector in Ghent was the largest in the Low Countries, and increasingly led to new investments in both spinning and weaving. Although cotton production started only around 1800, ten years later the Ghent factories reached annual production figures of more than 100,000 pieces. By 1826 more than 400,000 pieces of cotton were produced annually.[86] The number of textile workers involved increased correspondingly, from 1,400 in 1794 to 5,000 in 1807 and 11,600 by the time of Belgian independence in 1830.[87] The first steam engines were introduced into the Ghent textile industry during the closing years of the eighteenth century.[88] From the 1780s onwards cotton printing became the largest industry in Ghent, and soon employed thousands of labourers. In cotton spinning *perpetuals* and *jennys* had been in use before 1795,[89] 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.[90] By 1810 there were four steam engines in the Ghent industries, the number rising to 27 by 1820, 66 by 1830 and over a hundred before the middle of the nineteenth century (Table 6).[91] The early mechanisation of the textile industry in Ghent contrasts with the situation in

[85] Diederiks, 'Beroepsstruktuur', p. 49.

[86] Coppejans-Desmedt, 'De Gentse textielnijverheid', pp. 473-84, p. 508.

[87] Scholliers, *Wages*; Dhondt, 'L'industrie cotonnière'.

[88] Van Neck, *Les débuts*, p. 77 ff. and p. 101 ff.

[89] Coppejans-Desmedt, 'De Gentse textielnijverheid', pp. 151-2.

[90] Dhondt, 'L'industrie cotonnière'; Coppejans-Desmedt, 'De betekenis'.

[91] Van Neck, *Les débuts*, pp. 824-7.

Leiden. The first steam engine was introduced into wool spinning there in 1816. By 1830 there were only 4 engines in the city's woollen industry – a figure which did not exceed 21 until the second half of the nineteenth century.[92] Whereas Ghent would become the first industrial textile centre on the continent, Leiden experienced little industrial growth until the second half of the nineteenth century.

[Table 6]

Does energy provide an explanation for the changing industrial and economic fortunes of Ghent and Leiden? The reliance on peat might have blocked further economic development in Leiden from the later eighteenth century onwards, while coal boosted industrial innovation in Ghent. However, our analysis above of both the consumption (measured by way of excise taxes) and availability (measured through prices) of energy suggests otherwise. In terms of mere energy attainability, Leiden was better positioned than Ghent, not only during its Golden Age but also in the eighteenth century. Not only did it have access to cheaper energy in the form of peat, but the city also reached exceptionally high per-capita energy consumption levels, paralleled only in regions that could rely on the abundant availability of coal. In the following discussion we consider four explanatory frameworks for interpreting the relationship between energy and the economy in the cases studied. First, we look at the energy-deterministic model of economic development, then we consider alternative models based on geopolitics, technology and industrial organisation.

The high wage, cheap energy model

[92] Smit, 'De introductie', p. 529.

How, exactly, does the evolution of energy regimes in Ghent and Leiden established in this article fit into the stylised chronologies outlined by Malanima, Wrigley and Allen?[93] Based primarily on the British case they have proposed a model that consists of two chronologically distinct but causally connected transitions: 1) a first transition towards coal as a land-saving technology in the sixteenth century, and 2) a second transition towards coal as a labour-saving technology in the eighteenth and nineteenth centuries (see Table 7). According to Malanima, the first energy transition lifted the essential constraint on the pre-modern economy by saving on land, and therefore allowed for higher rates of urbanisation and greater labour productivity. This eventually gave rise to the conditions of a high-wage economy, which sparked the second transition.[94] Applying these stylised facts to the cases of Ghent and Leiden highlights the contrast between the two cases, as well as between the two and Britain. The two energy transitions in Ghent followed one another in such rapid succession as to become almost inseparable. In Leiden more than two centuries intervened between them, raising questions about their causal relationship. The energy-based model thus seems to be of limited value in explaining industrial developments in the Low Countries.

[Table 7]

Robert Allen has argued that the unique combination of high wages and cheap energy created the necessary incentives for British industrialists to embrace mechanisation: the combination of factor prices made substituting energy for labour more attractive than

[93] Kander, Malanima and Warde, *Power to the people*; Wrigley, *Energy and the English industrial revolution*; Allen, *The British industrial revolution*.

[94] Malanima, 'The limiting factor'; Allen, 'Why the industrial revolution'.

elsewhere.[95] The unique combination of factor prices in Britain has been highlighted by means of the ratio of labourers' wages to coal prices in Newcastle and London compared to those in other places worldwide. The higher ratio for Newcastle and London was seen as a demonstration of how factor prices worked in favour of mechanisation. Only Amsterdam, fuelled on peat, came close to the same wage-to-energy ratio as London.

It is possible to estimate the wage-to-energy ratio for Ghent and Leiden from the late sixteenth century until the beginning of the twentieth, based on wages and energy prices for both cities (Figure 10).[96] We find that this ratio was high in Leiden throughout the seventeenth and eighteenth centuries, even though it fell gradually until 1800. In fact, the Leiden ratio was comparable to that in Newcastle around 1700, and higher than that in London. The situation in Ghent was very different: there, the wage-to-energy ratio remained at a level roughly between those of London and Paris for most of the seventeenth and eighteenth centuries. From the beginning of the nineteenth century the ratio began to rise and surpassed the level of Leiden's probably around mid-century. This confirms that in the context of the early modern Low Countries Leiden was a 'high wage, cheap energy' economy: as a result of the abundant supply of peat in Leiden, its inhabitants continued to have recourse to a cheaper alternative than those of Ghent until well into the nineteenth century. The gradual rise of wood and peat prices over the course of the seventeenth, eighteenth and early nineteenth centuries slowly reduced the cheapness of energy in Leiden, but it never became more expensive than in Ghent.[97]

[95] Allen, *The British industrial revolution*, pp. 25-56 and pp. 80-105; Allen, 'The high wage economy: a restatement'; Humphries, 'The lure of aggregates.'

[96] Wages of unskilled labourers are used here, and compared to the price of the cheapest energy source in either city at each moment in time.

[97] De Zeeuw, 'Peat'; Van Zanden, 'Werd de Gouden Eeuw'.

[Figure 10]

As far as explaining mechanisation in the Low Countries is concerned, Allen's model has to be adapted in order to be applicable. In Leiden the demand-driven incentive for mechanisation was highest for over 200 years, yet this did not result in the mechanisation of its textile industry. In Ghent, mechanisation broke through from the 1790s onwards, even though the wage-to-energy ratio does not appear to have changed significantly during this period. Contrary to what the 'high wage, cheap energy' hypothesis would predict, the region with the labour-energy ratio most favourable to energy-intensive mechanisation innovated its industry the latest. Hence, other factors affecting the relationship between energy and industrialisation in the Low Countries must also have been at play.

Geopolitical and technological factors

What alternatives are there for the divergent trajectories of Ghent's and Leiden's industries? First, we consider the possibility that differences in the geopolitical positions of Leiden and Ghent (or Holland and Flanders, respectively) hindered the breakthrough of a mineral economy in Leiden, but not in Ghent. The argument that the proximity to coalfields directly influenced the potential for economic growth, still figures prominently in the literature on the industrial revolution.[98] Regarding the (early modern) Low Countries specifically, Allen referred to political divisions and high transport costs as the main reasons why coal from Belgium, the Ruhr or Newcastle was not used to power Amsterdam or the Dutch economy in general, thus

[98] Is has most recently been explored in a cliometric fashion by Fernihough and O'Rourke, 'Coal and the European industrial revolution'.

preventing the transition from an 'advanced organic economy' to a 'mineral' one.[99] In the eighteenth-century Southern Low Countries (Ghent) coal was both imported on a large scale from England and mined locally in the regions of Hainaut and Liège.[100] Although complaints against the raising of import duties on English coal from 1749 indicate that English coal was initially important, during the second half of the eighteenth century more than 90 per cent of the coal brought into the city of Ghent came from within the Austrian Netherlands itself.[101] The mining of coal in Hainaut and Liège expanded rapidly, and by 1800 the mines around Mons and Liège produced 2 million tons of coal per year: a low figure compared to that for Britain, where 15 million tons was produced annually, but higher than anywhere else in Europe at the time.[102] Transport via the Haine and Scheldt rivers, usually via Mons and Tournai, made Ghent an easy destination for the coal mined in the Borinage area. Its accessibility increased further with the construction of canals in the late eighteenth and early nineteenth centuries.[103]

In Holland, coal needed to be imported across larger geographical and political distances, a factor saddling it with high import duties.[104] Coal deposits in the Dutch region of

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[99] Allen, *The British industrial revolution*, p. 103.

[100] Coenen, *Carriers of growth*, pp. 199-231.

[101] This is clear from the excise revenues which distinguished between foreign and domestic coal: SAG, series 515. Also: Van Daele, 'Proeve', pp. 132-3.

[102] Pounds and Parker, *Coal and steel*, p. 97; Flinn, *The history of the British coal industry*, pp. 26-7. On the importance of the Belgian coal industry in the eighteenth century see Dejongh and Seghers, 'Een kleine natie in mutatie'; Van der Wee, 'The industrial revolution in Belgium'; Pollard, 'Industrialization'; Allen, *The British industrial revolution*, p. 82, p. 140; Hasquin, *Une mutation*; Douxchamps-Lefevre, 'Le commerce du charbon'.

[103] A particular bottleneck that could thus be circumvented was the need to cross the French border at Condé-sur-l'Escaut: Gillet, *Les charbonnages*.

[104] Van Zanden, 'Industrialization in The Netherlands'; Allen, *The British industrial revolution*, pp. 103-4; Murray and Silvestre, 'Integration in European coal markets'.

Limburg were deeper, harder to reach, and required more sophisticated mining technology – hence the late development of mining in this area only after 1850.[105] As a result, the coal consumed in the Northern Low Countries came in the main from Newcastle, Liège, the North of France or the Ruhr area, reaching Holland via the rivers Maas and Rhine through the ports of Rotterdam and Dordrecht, or via the North Sea through the port of Amsterdam.[106] A crucial difference in the geopolitical context of both cities' coal supply was political control over the supply chain. In Leiden supply was subject to Anglo-Dutch trade relations, which were often unreliable, whereas Ghent benefited commercially from the Austrian Netherlands' neutrality in the American Revolutionary War in 1776-1783. Leiden meanwhile suffered from the effects of the Fourth Anglo-Dutch War.[107] After the war commerce between the Dutch Republic and England quickly recovered, but was soon to be disrupted again in 1795, when the beginning of the French period of the Low Countries blocked British imports once again. The availability of coal from within the Austrian Netherlands not only reduced volatility in supply, but also allowed the urban, provincial and central governments to develop a mercantilist policy aimed at reducing transaction costs for the early industrialists in Ghent. The Estates of Flanders, the representative institution at the provincial level, which was housed in Ghent, undertook an ambitious policy of improving the roads and waterways outwards from Ghent throughout the eighteenth century, while at the same time raising import duties on English coal.[108] Although the network of barges in seventeenth-century Holland had been unsurpassed in its time, the

[105] Gales, *Delven en slepen*.

[106] Horlings, *The economic development*, p. 348; Mitchell, *European historical statistics*, pp. 381-91, pp. 428-36; Nef, *The rise of the British coal industry*, pp. 117-22; Sneller, *Geschiedenis van den steenkoolhandel*, pp. 92-6; Unger, 'Energy sources', pp. 239-45.

[107] Lenders, *Gent, een stad tussen traditie en verlichting*, pp. 45-7.

[108] Serruys, 'Urban networks on the move'.

road and waterway network surrounding Ghent had by the end of the eighteenth century become among the densest in continental Europe.[109] The fact that coal could also be supplied from within the Austrian Netherlands provided an incentive for investments and reforms that helped to lower transaction costs. The opposite scenario played out in Leiden, where a protectionist fuel policy adopted in 1834-1864 taxed coal heavily, as the Dutch government attempted to protect and stimulate the expansion of its domestic peat production.[110]

This geopolitical context helps to explain why Leiden did not transition towards a mineral economy only when it is combined with a second causal factor: the potential technological lock-in effect of peat. If peat and coal were truly interchangeable and could both lead to industrial mechanisation and the adoption of labour-saving technology, then only the lowest energy price mattered, and not the price of coal per se. However, if coal and peat were not equal and the way in which their power could be used for labour-saving purposes differed, then the different energy mixes and access to coal in Leiden and Ghent became a crucial variable in explaining their divergent economic outcomes. According to Jan Luiten van Zanden, peat and coal did not really differ from one another in terms of social savings – that is, the costs saved by a new technology compared to its next best alternative. Rather, the difference was in the spin-off effects of both. While the coal industry triggered investments in technical advance for draining mines, peat production formed a technological dead end. As M.A.W. Gerding has shown, labour productivity in the Dutch peat sector hardly increased

[109] Génicot, *Histoire des routes*; Blondé and Ballaux, 'Road transport'; De Vries, *Barges of capitalism*. Compare this with the slow changes in water infrastructure around Leiden in the eighteenth and nineteenth centuries: Smit, 'Leiden op stoom', p. 68.

[110] Van Zanden, 'The ecological constraints'; Gerding, *Vier eeuwen turfwinning*; Teijl, 'Brandstofaccijns en nijverheid'.

between 1650 and 1900.[111] Since peat was 'areal', extraction did not require techniques other than those already known from more traditional economic activity in agriculture, thus, preventing technological change.

Not only did the technological incentives provided by peat and coal differ within the sites of extraction themselves but coal also had beneficial effects in other sectors, most notably in the adoption of steam in the textile industry.[112] Although some attempts in the textile sector to produce steam engines powered by peat are documented for the Twente area in the Low Countries, there is no such evidence specifically for Leiden, nor do they appear to have been successful in the long run.[113] It is telling, for instance, that the Leiden textile entrepreneur, J.J. Krantz, used peat to heat his factory, office and home, while he relied on more expensive coal to power his steam engines, as is clear from his accounts.[114] An article in the 8 July 1850 issue of the *Algemeen Handelsblad* discusses the successful attempt to adapt a steam ship to peat: 'One will hear with interest, that the steam engine in the steamboat from Zwolle […], on its trip to Amsterdam, was powered by peat, and that this trip was very successful; the boat does not travel slower with peat than with coal; the machinery does not have to be changed […]. However, it is not possible to keep enough peat on the boat for both the outward and return journey; and therefore, because the administration for urban excises of Amsterdam prevents the establishment of a storage place for fuel at the docks, the return journey needs to be continued with coal.'[115] This suggests not only that modified steam engines were not very common in the Northern Low Countries, even by the middle of the nineteenth century, but also

[111] Gerding, *Vier eeuwen turfwinning*.

[112] Von Tunzelmann, *Steam power*.

[113] Boessenkool, 'De eerste stoommachine', p. 68.

[114] GAL, archives of J.J. Krantz & Zoon, no. 692.

[115] *Algemeen Handelsblad*, 08-07-1850, accessible on https://www.delpher.nl/.

that peat was still not an ideal energy carrier for powering machinery. Most engines needed intensive combustion, which could be obtained only by burning such a vast volume of peat that storage problems were created. Peat had proved to be a perfect carrier for land-saving purposes, but also much harder to harness for labour-saving developments through machine technology.

The organisation of industrial production

An alternative explanation to geopolitical and technological factors for the relationship between energy and mechanisation in Ghent and Leiden can be found in the organisation of the textile industry itself. Like the 'high wage, cheap energy' hypothesis, the organisational approach seeks to identify differences in the demand for mechanising technologies rather than in the supply of energy and technology. Two organisational aspects were necessary conditions for the introduction of mechanising technologies in the textile industry: the willingness of entrepreneurs to invest capital in mechanised production, and the ability to amass the labour required to operate and service the machines of the early industrial revolution.

Industrial mechanisation was, of course, not invented using steam or fossil fuels. It had already existed for a long time in the form of water and windmills – famously so in the case of the Northern Low Countries.[116] Traditional mechanical technology was often located in the countryside, where the ebbs and flows of wind and water were abundant but where labour was scarce. Millowners often worked independently of one another on a small scale within a decentralised system. Modern machinery powered by fossil fuels, on the other hand, enabled the centralisation of the production process into a single space where labour and energy were integrated under one roof.[117] The ability to procure sufficient labourers has long been

[116] Kaptein, *Nijverheid op windkracht*.

[117] Malm, *Fossil capital*.

considered a conditio sine qua non for industrialisation, as it was an important motivation for locating mechanised industries in cities where labour was freely available.[118] It has therefore been argued by labour historians that proletarianisation was a leading force – a precondition even, rather than a result – of industrialisation.[119]

During the second half of the eighteenth century the re-organisation of labour and production was gradually picking up speed in the Low Countries. The process sparked debates and political struggle over the liberalisation of commodity markets, the abolition of local tolls and import duties, and the abolition of corporations.[120] The political economy in Ghent and Leiden was, however, quite different. In Ghent, a large group of wholesale merchants and entrepreneurs increasingly gained political power in the city and used their influence to enact free market policies.[121] In 1755 the physiocrat Jean Jacques Vilain XIIII became mayor of Ghent and carried out a policy favourable to the new industries.[122] From that point onwards, a political balance was sought between industrial and aristocratic interests, while industrialists gained control over economic policy thanks to the newly founded Chamber of Commerce. Occasional surveys and travel reports show how, prior to the introduction of fossil-based

[118] Mokyr, *Industrialization*; Dhondt, 'Notes sur les ouvriers.'

[119] For instance see: Safley and Rosenband (eds.), *The workplace*.

[120] These conflicts were considerably more complex than a straightforward opposition between guilds favouring small-scale industrial production and free-market-oriented capitalists. The textile industries in both Ghent and Leiden in the eighteenth century were only partially organised in guilds, and even when they were, these guilds often proved highly flexible in incorporating capitalist modes of production within their structures. Heirwegh, 'Les corporations'*;* Vermaut, 'De textielnijverheid in Brugge'; Lis and Soly, 'Subcontracting'; Lis and Soly, 'Export industries.'

[121] Lenders, *Gent, een stad tussen traditie en verlichting*; Coppejans-Desmedt, 'De Gentse textielnijverheid'; Heirwegh, *Les corporations.*

[122] Lenders, *Gent, een stad tussen traditie en verlichting*, pp. 165-7.

mechanisation, the concentration of labour in manufactures was well underway.[123] In 1764 nine textile 'bosses' employed more than 1,100 labourers in their factories.[124] By the 1780s a small group of entrepreneurs had achieved a high degree of control over the resources and labour involved in the production process, creating a context of concentration in which mechanisation could successfully be introduced.[125]

Some of the industrial entrepreneurs in eighteenth-century Leiden, such as the cloth manufacturer Jan van Heukelom, argued for the abolition of corporations and the introduction of industrial mechanisation in the same way as their counterparts in Ghent did. However, until the beginning of the nineteenth century they do not seem to have gained the same level of political influence to be able to establish a policy that favoured a scaling up of labour and capital concentrations in manufacture. Craft guilds were abolished in Leiden in 1798, and a Chamber of Commerce and Industry was founded in 1816.[126] Although some larger manufactories emerged in eighteenth-century Leiden, they did not reach the same level of expansion as in Ghent, and they would decline, together with the urban textile industry as a whole, during the second half of the eighteenth century.[127]

Differences in the organisation of production between the two cities can at least in part be attributed to the different textiles produced in Ghent and Leiden. While Leiden largely remained a wool town throughout the entire period under scrutiny, Ghent became a cotton town, gradually abandoning its wool and linen industries in the eighteenth and nineteenth centuries. The adoption of steam for industrial mechanisation proceeded more swiftly in the

[123] See Dérival, *Voyageur* (1782-83).

[124] Moureaux, *La statistique*, pp. 311-2.

[125] Coppejans-Desmedt, 'De Gentse textielnijverheid'.

[126] Smit, 'Leiden op stoom'; Quispel, 'Aspecten van de industrialisatie'

[127] Tjalsma, 'Leidse textielarbeiders'.

cotton sector – 'the wonder industry of the Industrial Revolution.'[128] The strong cotton fibres generally proved better suited to early mechanical treatment from spinning mules and power looms.[129] As a 'new industry' the cotton sector was mainly organised outside the corporate guilds. The first industrial entrepreneurs in Ghent had made their fortunes in the proto-industrial linen trade, and in the final decades of the eighteenth century some of them began to invest their capital in the establishment of large-scale factories.[130] The first *indiënneries* (cotton printing factories) of Judocus Clemmen, Abraham Voortman and Frans De Vos in Ghent employed several hundred labourers.[131] Peter Kriedte has observed that the production process in these new industries, such as the cotton industry, but also in glass making, tobacco manufacturing and pottery firing, was much more centralised than in traditional craft industries – a crucial condition, he argued, for the transition from mercantile to industrial capitalism.[132]

Although the material disadvantage in the quality of fibres did not prevent some wool producers and merchants in both Ghent and Leiden from investing in steam mechanisation,[133] the wool industry in both towns remained mainly based on small-scale production.[134] While cotton manufactures in Ghent quickly adopted spinning mules, power looms and cylinder presses from 1797 onwards, the first steam engines appeared in Leiden only after 1816. Despite conditions in terms of the factor prices of energy and labour having been more conducive to

[128] Allen, The British industrial revolution, p. 182.

[129] Farnie, 'Cotton'.

[130] Vandenbroeke, 'Proto-industry in Flanders'.

[131] Coppejans-Desmedt, 'De Gentse textielnijverheid', pp. 451-4.

[132] Kriedte, *Peasants, landlords and merchant capitalists.*

[133] Coppejans-Desmedt, 'Pogingen tot opbeuring'; Smit, 'Leiden op stoom'. For a good example of how the woollen industry did not by definition prevent industrialisation is the early industrial wool town of Verviers in Walloon Belgium see Van der Wee, 'The industrial revolution in Belgium'.

[134] DuPlessis and Howell, 'Reconsidering'.

mechanisation in Leiden than in Ghent, the industrial divergence between the two cities suggests that other factors mediated this relationship. In Ghent the political and economic influence of a small group of textile entrepreneurs had already given rise to the conditions of large labour concentration as a first step towards factory production. The political struggles in Ghent and Leiden that preceded and determined these outcomes probably played an important role in the demand for fossil-based technology that allowed this concentrated labour to become more productive and profitable.

Conclusions

The role of energy looms large in historical debates on economic development.[135] Wrigley in particular has proposed that the transition from an organic to a mineral economy was an essential precondition for industrialisation and modern economic growth.[136] Allen has argued that the unique combination of cheap energy and expensive labour was crucial in prompting the British industrial revolution.[137] This article has attempted to contribute to our understanding of energy in pre- and early industrial development by presenting a comparative study of two cities in the Low Countries. Thus far the Low Countries have at best played a mainly supporting role in this debate. On the one hand, the presence of cheap energy in the form of coal deposits in Belgium (the Southern Low Countries) has been invoked in support of Allen's model of industrialisation. On the other hand, the lack of an efficient transport corridor to the Ruhr or the Belgian coal regions has been used to explain why industrialisation did not break through in the Netherlands (the Northern Low Countries).

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[135] Smil, *Energy in world history*; *Energy and civilization*; *Growth*.

[136] Wrigley, *Energy and the English industrial revolution*; *The path to sustained growth*.

[137] Allen, *The British industrial revolution*, pp. 25-56, pp. 80-105.

The reconstruction of energy consumption in two cities in the Low Countries, Ghent and Leiden, over the course of the seventeenth, eighteenth and nineteenth centuries allows us to revisit this understanding of the role of energy in economic development. The case of Ghent (Belgium), the first industrial textile city outside Britain, fits relatively well into the British model of industrialisation. Coal was consumed there in modest quantities from at least the early seventeenth century until the middle of the eighteenth. Following a period of gradually rising prices for fuelwood and charcoal, coal became the cheapest energy source around 1750 and rapidly expanded its share of the energy mix during the following decades. In the final years of the eighteenth century the city's reliance on coal facilitated its rapid take-up of steam-driven technology from Manchester.

If Ghent's early access to coal and its rapid industrialisation appear to confirm the relationship between cheap energy and economic development, the comparison with Leiden complicates the narrative. From the seventeenth until the middle of the nineteenth centuries the city of Leiden in the Northern Low Countries consumed more energy per capita and per unit of economic output than did Ghent. This was possible because of Leiden's early transition to a peat-based energy regime, which took place before the start of the seventeenth century. The access to abundant peat ensured that the city had recourse to cheaper energy sources per GJ than Ghent did until well into the nineteenth century. The cheap-energy economy of early modern Leiden did not lead to industrialisation or mechanisation as in eighteenth-century Britain or Ghent. However, the impressive expansion of Leiden's textile industry during this period, as well as its high living standards, high per capita output and expanding consumer culture, most likely profited from the availability of cheap energy for both industrial and domestic use. The margins for growth in a pre-industrial context were perhaps determined less by the technology of mechanisation than by willingness and the ability to consume available stocks of fossil energy.

The comparative study of Ghent and Leiden reveals important difficulties in transposing existing models of the relationship between energy transitions and economic development to new cases. The transition to a cheap-energy economy in Holland was associated with economic growth, but not with mechanisation. On the other hand, the rapid mechanisation process in Ghent was associated not with a cheap-energy economy (relative to that of Leiden), but more specifically with a cheap-coal economy. The greater direct control over the supply chain of coal probably contributed to a political economy in the Southern Low Countries more conducive to industrial development. Moreover, industrial entrepreneurs' control over labour was greater in Ghent than in Leiden, which might have made more likely the transition to a fossil-fuelled system based on the concentration of labour.