Energy Cycles: Nature, Turning Points and Role in England Economic Growth from 1700 to 2018

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Abstract
Business cycles are among the most discussed topics in social sciences. Environmental changes, heatwaves and natural disasters as consequences of anthropogenic activities are headwinds to future economic growth and development. There is an ongoing debate on environmental degradation and its socio-economic impact. Here we investigate the existence of primary energy (coal, gas, oil, nuclear, solar, thermal, wind) cycles in England from 1700 to 2018. Using turning points methodology (Harding & Pagan, 2002), we isolate energy cycles and explain their phase characteristics. Offering empirical evidence of energy cycles existence should assist policymakers to gain additional quantitative knowledge to understand and contain business cycles. Fossil fuels energy cycles are closely linked to business cycles, but renewable energy cycles are pushing forward, targeting the leading role. Energy cycles are the missing link in the literature needed to understand business cycles and future economic development. In this study, we supply knowledge for understanding energy cycles and their relationship to the business cycles. The estimated concordance index reveals a systematic relationship between energy and business cycles with conclusive results. Energy cycles in this century will become a major force driving socio-economic events. Managers in the firms and policymakers on the macro-level will need knowledge on energy cycles since tracking energy cycles soon will become more important to tracking business cycles. To this end, our study contributes to the study of energy cycles as the source of business cycles.

Keywords
Energy cycles, Turning points, Concordance index, Primary energy, Business cycles

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Introduction

The relationship between energy and growth is a subject of intensive inquiry. Until now, research on this subject has concentrated on the relationship between CO2 (carbon dioxide) emissions and economic growth, as well as the impact of electricity and renewable energy on economic growth. Not only for policymakers but also for practitioners preparing for the energy transition, it is critical to understand the role of energy in economic growth. Economic growth models and policies must adapt to changing conditions, resulting in the development of a new growth model.

The role of energy in growth is studied in Keen et al. (2019) using energy-based (exergy) production function models (Heun & Brockway, 2019). Our study aims to investigate, quantify, and explain the turning points in energy consumption measuring (for the first time that we are aware of) and deriving energy cycles. Our findings confirm the concept of energy cycles. Energy cycles exist, and they show different mechanics for different energy sources. Without establishing energy cycles, policymakers and business practitioners will be limited in designing efficient economic policies to achieve growth. Assuring future sustainable development demands quantitative knowledge on energy cycles. The article's statistical analysis of time-series data for the United Kingdom (UK) from 1700 to 2018 supports the energy cycles idea. Contribution to the field of knowledge results from its use of the most extensive time-series data on energy consumption (1700–2018) and the most advanced modelling approaches (cycle measurement). To shed new insight on energy cycles, we evaluate primary energy cycles in the UK using data on primary energy consumption. We seek to build a novel study field by combining historical time series data, cutting-edge cycle modelling tools, and a modified Harding and Pagan approach (Cardinale & Taylor, 2009).

In seminal publications (Ayres et al., 2003; Ayres & Warr, 2005; Ayres & Voudouris, 2014; Warr et al., 2010; Keen et al., 2019; Santos et al., 2018), the authors propose a new form of aggregate Cobb-Douglas function (Cobb & Douglas, 1928). Their work reaffirms energy's significance in production, paving the door for future 'energy-based' growth models. Positive energy has been shown to contribute to economic growth in 66 nations between 1986 and 2005 (Sharma, 2010). There is evidence to imply that a link exists between energy demand/supply and economic growth (Apergis et al., 2010; Apergis & Payne, 2009a, 2009b, 2009c; Ozturk & Acaravci, 2013; Wolde-Rufael, 2009, 2014; Coers & Sanders, 2013; Richard, 2012; Jalil, 2014; Mohammadi & Parvaresh, 2014).

However, the data regarding the precise nature of the relationship between energy supply/demand and economic growth is mixed. Most existing research points to a positive relationship between energy and growth. The evidence for energy’s efficacy in growth differs considerably, ranging from research supporting the energy-growth theory to studies demonstrating energy-growth decoupling (Sharma et al., 2019). (Moreau & Vuille, 2018). Economic growth and energy use are intricately connected, as has long been recognised. Energy consumption increases as the economy grows; when energy is scarce, GDP (gross domestic product) growth slows. According to studies conducted by Foxon (2018), Fouquet (2008, 2018, 2019), this was the actual scenario that existed during the formation of ancient towns and trade markets.

Recently, Sharma et al. (2019) concluded a multi-year study project in which they investigated the supply and demand for 55 different types of energy in 30 different sectors across 146 different nations. According to the most current global energy outlook, we are witnessing a decoupling of economic growth and energy demand. Not only is it critical for macroeconomic management to understand the underlying relationship between energy and growth, but it is also critical for company managers to address energy cycles appropriately soon. Our study emphasises the critical role of empirical evidence in fully comprehending the nature of energy cycles. The long-run relationship between energy cycles and growth in the UK over the previous three hundred years is examined here.

The findings of this study cast doubt on the standard concept of a long-term energy-growth link. Between countries, the energy cycles-growth nexus is more important than the energy-growth link itself. The level of synchronisation between primary energy consumption (cycles) and economic growth determines future growth rates. To understand the nature of the business cycles first, we must explore energy cycles. It is volatility in energy consumption to drive economic fluctuations significantly. There exists a strong causality link between economic shocks and energy consumption – a bidirectional link. Movements in energy prices cause global fluctuations in energy consumption as well economic fluctuations and potential crises. Energy cycles, in their nature, can be regarded as supranational cycles having global socio-economic implications. Empirical evidence on the existence of countries energy cycles, like the one we isolate for the UK, provide quantitative knowledge and proof to support future studies in the field of energy cycles.

We intend to build on prior research on the energy-growth nexus, which has shown inconclusive results. The primary objective of this study is to identify and explain (using empirically rigorous data) energy cycles and their link with growth. The central research question is to explain the role of energy cycles on economic growth in the past and future. Our research aims to establish a causal link between energy cycles and growth. To do this, we suggest a modified method for energy cycles identification. A novel element of our research is in measuring primary energy cycles and their synchronisation to growth. Our innovative approach in the subject of energy cycles-growth link is motivated by recent developments. To accomplish this, we employ long time-series data and state-of-the-art cycles measuring techniques from 1700 to 2018 in the UK.
The paper begins with a survey of the literature on the energy-GDP (gross domestic product) nexus. Section three discusses the material and method used throughout the study. Section four has a detailed description of the empirical results. Section five summarises and discuss the study's findings. The conclusion highlights the study's major results and practical contributions, as well as making recommendations for further research.

**Literature Review on Energy and Growth**

The energy cycle is not an area explored in literature. Rather, the relationship between energy and economic growth is studied. However, the results of the research are not consistent and unambiguous. The first step in modelling energy price shocks in a Real Business Cycle framework was examined by Kim and Loungani (1992).

The literature on the subject is confused about the effects of the energy transformation. On the one hand, it points to opportunities for economic growth, and on the other hand, it points to excessive financial outlays. Moreover, in 2005, most EU countries decoupled economic growth from energy consumption.

Observation of the global energy transition leaves no doubt that the rise of renewables will change the relationship between countries and drive key changes in the world's economies (IRENA, 2019). Moreover, economic growth will be facilitated for countries that are able to innovate more in renewables, batteries, and electric cars (Hafner & Tagliapietra, 2020). According to an OECD report 2017, economic growth must be looked at in the long term, inclusive growth must be considered, and sources of growth must be economically, socially, and environmentally.

An analysis of the 10 largest energy-consuming countries in the world shows a positive relationship between economic growth and energy consumption, although there are significant differences between the economic states of each country (Shahbaz et al., 2018).

Looking at 75 net energy-importing countries for the period 1990 to 2012, they find that there is a positive and statistically significant relationship between energy consumption and economic growth over the long term. When a country’s dependence on imports decreases, then energy consumption contributes to economic growth (Kim & Loungani, 1992). Also, looking at the USA economy argued a strong correlation between growth in electricity use and GDP (Arora & Viskovsky, 2014).

Considering the Swedish economy, Stern and Kander (2012) confirm that the main drivers of economic growth in the 19th and early 20th Centuries were increases in energy use as well as energy – augmenting technological change. Stern et al. (2016) highlighted that electricity access is likely not sufficient for economic growth, but they find that electricity use and GDP are those variables that share the same trend.

Considering Bulgarian economy 1999-2016, Vasilev (2018) introduce a pro-cyclical endogenous utilisation rate of physical capital stock into a real business cycle model augmented with a detailed government sector. They investigated the energy use for cyclical fluctuations in Bulgaria, considering the quantitative importance of the endogenous depreciation rate and the capital use mechanism operating through energy use. They find that a positive shock to energy prices in the model works as a negative technological shock.

The study of China's economy showed while energy consumption causes economic growth by Granger's method in the short run, but the opposite is true in the medium run. However, in the long run, a bidirectional causal relationship is proven (Ha et al., 2018).

Interesting results were presented by analysing nineteen selected African countries from 1971 to 2014. Results show an asymmetric relationship between energy consumption and economic growth. Moreover, it depends on the phases of the economic cycle. Given a period of economic expansion, positive shocks to energy consumption have a positive and significant effect on economic growth in the long run but have a weak positive effect in the short run. In contrast, Negative shocks in energy consumption have a negative and significant impact on economic growth in the long run but already have a significant and positive impact in the short run (Kouton, 2019). Considering the business cycle in the US economy, it was found that permanent shocks explain the bulk of the variations in energy consumption and output at business cycle horizons (Narayan, 2011).

The study on the example of Turkey indicates that there is no evidence of causality between energy consumption and GDP (Altinaya, 2004).

**Material and Methods**

The principal goal of our study is to isolate energy cycles using long time series data for the UK. The first step in decomposing time series in a search for energy cycles is to use Bry & Boschan (1971), Harding & Pagan (2002, 2003) turning point procedure. To this end, annual data are converted to quarterly data (higher frequency) using a Chow-Lin regression frequency conversion (Chow & Lin, 1971). Identifying turning points in time series data to isolate cycles requires high-frequency data (quarterly). Converted quarterly data were checked against original annual data fitting at best with a correlation coefficient of 0.99. Converted quarterly data show high reliability and no bias, so to proceed with cycle extraction according to standard procedures for time series data decomposition. We use data sources to construct this study database, including Department for Business, Energy, and Industrial Strategy (2019), Church (1986; Flinn & Stoker, 1984; Fouquet, 2008; Prest & Adams, 1954; Stone...
et al., 1954). The software and procedure we use here in the analysis is STATA 16MP and Bracke (2012) business cycle dating algorithm.

To study energy cycles, this study uses a battery of standard econometric filters (Cardinale & Taylor, 2009; Pollock, 2015), unobserved component decomposition (Harvey, 1990) and spectral analysis (Sella et al., 2013). Energy cycle decomposition requires extended time-series data, so data availability is the key factor for a country's candidate. Extensive reviews on historical energy production and consumption global databases put forward Great Britain (UK) as a suitable candidate for the analysis. Beyond data availability, the UK is a perfect study candidate since its key role in the industrial revolution process and leadership role in energy transition and decarbonisation after 1960. Another prospective country is the US, but the data for the US are available from 1775 on a five-year basis and only after 1949 on an annual and monthly basis. Cycle extraction demands high levels of data reliability, and thus the UK is selected as a candidate for the study. Cycle decomposition demands at least data beyond the Kondratieff cycle (Modis, 2017) of 60 years. Due to the energy transition witnessed after 1960, primary energy cycles could not be examined adequately. Since the purpose of the study is to assert (or decline) primary energy cycle existence, an extended time series data sample is needed. For this purpose, this study uses Fouquet (2020) database. This study presents a novel attempt to isolate primary energy cycles, so this pioneering approach involves high data reliability. Fouquet (2020) offers historical energy data for the UK from 1700 to 2018 on UK energy consumption, energy prices and carbon dioxide emissions. Literature on cycles in economics look at the pattern, stages in economic activity to isolate a long-run tendency. Forecasting economic activity is the final goal in measuring economic activity and growth cycles (Zarnowitz & Ozyildirim, 2006). Prolonged growth cycle phases cause jumps in the series bringing the level of economic activity on higher/lower dynamic paths. It is the purpose of this study to scan at patterns, phases that could explain amplitudes (expansion, contraction) in primary energy consumption. To isolate and understand primary energy cycles could help infer the process of energy transition and its determinants. This could help learn how primary energy consumption changed over time to mitigate growth externalities. The starting point to decarbonisation is to prove or disprove primary energy cycles.

Non-renewable primary energy is a driving growth factor for a long. This study decomposes time series data on primary energy availability and consumption in the UK from 1700 to 2018. To this end, the study uses data on coal, petroleum, natural gas, nuclear energy, hydro energy, wind and solar energy, thermal energy, and bioenergy in the UK. A study of an individual cycle starts with the graphical data examination. Figure 1 shows the availability and consumption of primary energy in the UK from 1700 to 2018 (inland consumption for energy use).

Fig. 1. Availability and consumption of primary energy in the UK, 1700-2018
Figure 1 shows a singular exponential growth shape in primary energy consumption. The graph portrays the dynamics in energy transition, from bioenergy to solar energy, through all nine types of energy sources. Coal was the primary source of energy from 1700 to 1971 after being replaced by petroleum (1971), natural gas (1993) and nuclear energy (2016). However, the energy transition from fossil fuels to renewable energy is still far going (see Figure 2).

Figure 2 shows energy consumed from different sources in the UK over three centuries. The booming of renewable energy sources is evident after 1990. The amount of energy consumed coming from fossil fuels is still dominant. Not only, in the year 1700 in the UK, fossil fuels accounted for 71.14% of the total energy consumed. In 2018, energy consumed in the UK occurring from fossil fuels was 80.41%. The share of renewable energy in the total energy consumed in the UK increased from 8.78% in 1989 to 17.28% in 2018. Such an important shift in energy transition decreased total carbon emissions (gas, non-fuel, oil) from 582 million tonnes in 1989 to 366 in 2018. Carbon emissions dropped by -37.11% or a -1.58% annual decline rate. That is, an insuring sign for the decarbonisation undertaking in England.

Results

Table 1 displays coal energy cycles in the UK from 1700-2018 using the cycle dating algorithm of Harding & Pagan (2002). The algorithm, through time-series data turning point identification, isolates 32 contraction phases (peak to trough) and 32 expansion phases (previous trough to peak). The expansion phase, on average, lasts 29 quarters and the contraction phase 7 quarters. The expansion phase, as expected for the coal role in UK past growth, is four times the average contraction cycle length. The average cumulative movement in expansion is sixteen times the magnitude of the cumulative movement in contraction (longer average duration). The average amplitudes for expansion and contraction are similar in magnitude. The average amplitude for expansion is 20.3% and contraction -11.4%. A fall in coal consumption (contraction) is almost twice matched during the expansion phase. The downfall in coal consumption is quickly replaced (and surpassed) by a strong upswing in coal consumption. This points to the Pareto inefficiency in coal consumption since a decline in the coal consumption (the contraction phase) is replaced by over increased coal consumption (expansion phase) and not by alternative sources of energy. For downswings, the average cumulative movement in coal consumption is -57.9%. Thus, the cumulative decline
of coal consumption during contraction amounts to -57.9%. Actual loss in coal consumption (-57.9%) is far below actual gains in coal consumption (+1601.3%) during respective phases. Excess estimation in coal consumption during contraction and expansion phases reflects the speed (dynamics) of change in each phase. High positive divergence (excess in the expansion of 160%) reflects speedy revival in the initial part of an expansion phase. During the contraction phase, an excess measure (high negative divergence -269%) reveals a rapid decline in coal consumption in the early stage of a downswing.

Tab. 1. Turning Points and Coal Cycles in the UK from 1700 to 2018

| Peak Dates | Trough Dates | Contraction Duration (in quarters) | Expansion Duration (in quarters) | Cycle Duration (in quarters) |
|------------|--------------|-----------------------------------|----------------------------------|-----------------------------|
| 1723Q4     | 1724Q4       | 4                                 | 164                              | 168                         |
| 1765Q4     | 1766Q4       | 4                                 | 252                              | 256                         |
| 1829Q4     | 1830Q4       | 4                                 | 280                              | 284                         |
| 1900Q4     | 1901Q4       | 4                                 | 24                               | 28                          |
| 1911Q4     | 1912Q4       | 4                                 | 12                               | 16                          |
| 1913Q4     | 1914Q4       | 4                                 | 8                                | 8                           |
| 1917Q4     | 1919Q4       | 8                                 | 12                               | 20                          |
| 1920Q4     | 1921Q4       | 4                                 | 4                                | 8                           |
| 1924Q4     | 1926Q4       | 8                                 | 12                               | 20                          |
| 1927Q4     | 1928Q4       | 4                                 | 4                                | 8                           |
| 1929Q4     | 1932Q4       | 12                                | 4                                | 16                          |
| 1937Q4     | 1938Q4       | 4                                 | 20                               | 24                          |
| 1943Q4     | 1945Q4       | 8                                 | 20                               | 28                          |
| 1946Q4     | 1947Q4       | 4                                 | 4                                | 8                           |
| 1951Q4     | 1952Q4       | 4                                 | 16                               | 20                          |
| 1956Q4     | 1959Q4       | 12                                | 16                               | 28                          |
| 1960Q4     | 1962Q4       | 8                                 | 4                                | 12                          |
| 1963Q4     | 1967Q4       | 16                                | 4                                | 20                          |
| 1968Q4     | 1969Q4       | 4                                 | 4                                | 8                           |
| 1970Q4     | 1972Q4       | 8                                 | 4                                | 12                          |
| 1973Q4     | 1974Q4       | 4                                 | 4                                | 8                           |
| 1977Q4     | 1978Q4       | 4                                 | 12                               | 16                          |
| 1979Q4     | 1982Q4       | 12                                | 4                                | 16                          |
| 1983Q4     | 1984Q4       | 4                                 | 4                                | 8                           |
| 1987Q4     | 1990Q4       | 12                                | 12                               | 24                          |
| 1991Q4     | 1997Q4       | 24                                | 4                                | 28                          |
| 1998Q4     | 1999Q4       | 4                                 | 4                                | 8                           |
| 2001Q4     | 2002Q4       | 4                                 | 8                                | 12                          |
| 2003Q4     | 2004Q4       | 4                                 | 4                                | 8                           |
| 2006Q4     | 2009Q4       | 12                                | 8                                | 20                          |
| 2010Q4     | 2011Q4       | 4                                 | 4                                | 8                           |
| 2012Q4     |              | 4                                 |                                  | 8                           |

Duration
(in quarters)
Expansion 29
Contraction 7

Amplitudes (in %)
Expansion 20.3
Contraction -11.4

Cumulation (in %)
Expansion 1601.3
Contraction -57.9
We isolate 33 peaks and 32 troughs in the coal cycles during 1700-2018. Cycles in coal consumption did not dominate from 1700 to 1900, with most of the coal cycles registering between 1900-2012. After 2012, coal consumption registered a steep and continuing contraction phase with no revival in sight. For comparison, the average contraction phase over the whole period is seven quarters, and the last contraction phase alone, after 2012, is lasting for six years now. The role of coal in the UK economic activity is certainly becoming less important, and there is no sign of turning back. Coal as an energy source is the one taking the biggest hit in the UK energy transition since 1960 (Figure 3).

For natural gas consumption, we use data since 1960 when gas consumption share in total energy consumption was about 3% (1960), reaching 39.2% in 2018. The gas consumption curve in the UK from 1700 to 2018 is exponential, with close to zero consumption from 1700 to 1900 with the fastest growth after 1960. Table 3 shows gas energy cycles characteristics for the UK.

| REFERENCE DATES | DURATIONS IN QUARTERS |
|-----------------|-----------------------|
| Peak            | Trough                |
| 1964Q1          | 1964Q2                |
| 1979Q4          | 1980Q4                |
| 1981Q4          | 1982Q4                |
| 1987Q4          | 1989Q4                |
| 1991Q4          | 1992Q4                |
| 2000Q4          | 2002Q4                |
| 2004Q4          | 2006Q4                |
| 2008Q4          | 2009Q4                |
| 2010Q4          | 2014Q4                |
| 2016Q4          | 2017Q4                |
| Cycle           |                       |
| Peak to Trough  | 1                      |
| Contraction     | 4                      |
| Expansion       | 9                      |
| Previous Trough | 62                     |
| Cycle from      | 66                     |
| Previous Peak   | 63                     |
| Peak from       | 10                     |
| Previous Peak   | 10                     |

Source: Authors' own research

Fig. 3. Turning Points in the UK Coal Consumption, 1700-2018 (coal cycles)

Source: Authors' own research

Tab. 2. Turning Points and Gas Cycles in the UK from 1700 to 2018
Duration (in quarters)
- Expansion: 18.2
- Contraction: 6.66

Amplitudes (in %)
- Expansion: 91.5
- Contraction: -7.27

Cumulation (in %)
- Expansion: 3507.8
- Contraction: -51.9

Excess (in %)
- Expansion: -718.6
- Contraction: -269.3

Source: Authors' own research

We isolate ten peaks and eleven troughs in the gas cycles (Figure 4). Turning points in Table 2 and Figure 4 are fitting well the actual gas consumption data in the UK. That gives the opportunity to approximate the dynamics of gas cycles with a high level of confidence. The study identifies ten full gas cycles from 1960 to 2018. The mean duration of expansion is 18.2 quarters and contraction phase 6.66 quarters. The standard deviation for the contraction phase is 3.96 and 17.2 for expansion. The longest recession lasted 16 quarters and the longest expansion 62 quarters after 1964Q2. The expansion phase is considerably longer to contraction following a general asymmetric dynamic as in business cycles. Upswing (expansionary phase) displays positive duration dependence with mean duration 18.20 to 17.2 standard deviations. Contraction episodes show a mean duration of 6.66 to 3.96 standard deviation. Both expansion and contraction phases in gas consumption display positive duration dependence (mean duration > standard deviation). That suggests, both phases show a higher probability to end with duration (non-persistence). Average cumulative losses for contraction are -51.9% and gains during expansion 3507.8%. Cumulative losses in the contraction phase are significantly lower than gains. The highest expansion amplitude is 91.5%, and contraction -7.27%. We observe a considerably larger depth of the expansion phase. Negative divergence (-718.6) during expansion point to sluggish recovery from the start and (-269.3) swift decline at the start of the contraction period.

Source: Authors' own research

Our model separates 68 peaks and 68 troughs in the hydro energy consumption (Figure 5), while in Table 3, turning points are presented and discussed.

![Fig. 4. Turning Points in the UK Natural Gas Consumption, 1700-2018 (gas cycles)](source)

Source: Authors' own research
Fig. 5. Turning Points in the UK Hydro Energy Consumption, 1700-2018 (hydro cycles)

Source: Authors' own research

Figure 5 displays three distinct intervals in the hydro energy consumption from 1700-2018. The first interval is from 1700 to 1760, the second lasting from 1800 to 1830 and the third from 1920 to 2018. The majority of the registered turning points fall into these three intervals.

Tab. 3. Turning Points and Hydro Energy Cycles in the UK from 1700 to 2018

| REFERENCE DATES | DURATIONS IN QUARTERS |
|-----------------|------------------------|
| Peak            | Trough                 | Contraction | Expansion | Cycle |
| Peak to Trough  | Previous Trough to this Peak | Trough from Previous Trough | Peak from Previous Peak |
| 1701Q4          | 1700Q4                 | 4           | 15         | 8     | 11    |
| 1704Q3          | 1702Q4                 | 7           | 16         | 10    | 9     |
| 1706Q4          | 1705Q2                 | 6           | 18         | 11    | 12    |
| 1712Q3          | 1711Q1                 | 6           | 18         | 12    | 11    |
| 1714Q4          | 1713Q2                 | 6           | 15         | 9     | 9     |
| 1717Q3          | 1716Q1                 | 6           | 17         | 11    | 11    |
| 1719Q4          | 1718Q2                 | 6           | 15         | 9     | 9     |
| 1722Q3          | 1721Q1                 | 6           | 17         | 11    | 11    |
| 1724Q4          | 1723Q2                 | 6           | 15         | 9     | 9     |
| 1727Q4          | 1726Q1                 | 7           | 18         | 11    | 12    |
| 1730Q3          | 1729Q1                 | 6           | 18         | 12    | 11    |
| 1732Q4          | 1731Q2                 | 6           | 15         | 9     | 9     |
| 1735Q3          | 1734Q1                 | 6           | 17         | 11    | 11    |
| 1737Q4          | 1736Q2                 | 6           | 15         | 9     | 9     |
| 1740Q4          | 1739Q1                 | 7           | 18         | 11    | 12    |
| 1743Q3          | 1742Q1                 | 6           | 18         | 12    | 11    |
| 1745Q4          | 1744Q2                 | 6           | 15         | 9     | 9     |
| 1748Q3          | 1747Q1                 | 6           | 17         | 11    | 11    |
| 1750Q4          | 1749Q2                 | 6           | 15         | 9     | 9     |
| 1753Q3          | 1752Q1                 | 6           | 17         | 11    | 11    |
| 1755Q4          | 1754Q2                 | 6           | 15         | 9     | 9     |
| 1758Q4          | 1757Q1                 | 7           | 18         | 11    | 12    |
| 1800Q4          | 1760Q1                 | 163         | 175        | 12    | 168   |
| 1803Q1          | 1801Q4                 | 5           | 172        | 167   | 9     |
| Quarter   | Duration | Expansion | Contraction | Amplitudes | Expansion | Contraction | Cumulation | Excess |
|-----------|----------|-----------|-------------|------------|-----------|-------------|------------|--------|
| 1805Q4    | 1804Q1   | 7         | 16          | 9          | 11        |             |            |        |
| 1808Q1    | 1806Q4   | 5         | 16          | 11         | 9         |             |            |        |
| 1810Q4    | 1809Q1   | 7         | 16          | 9          | 11        |             |            |        |
| 1813Q1    | 1811Q4   | 5         | 16          | 9          | 11        |             |            |        |
| 1815Q4    | 1814Q1   | 7         | 16          | 9          | 11        |             |            |        |
| 1818Q1    | 1816Q4   | 5         | 16          | 11         | 9         |             |            |        |
| 1820Q4    | 1819Q1   | 7         | 16          | 9          | 11        |             |            |        |
| 1823Q1    | 1821Q4   | 5         | 16          | 11         | 9         |             |            |        |
| 1825Q4    | 1824Q1   | 7         | 16          | 9          | 11        |             |            |        |
| 1828Q1    | 1826Q4   | 5         | 16          | 11         | 9         |             |            |        |
| 1870Q3    | 1829Q1   | 166       | 175         | 9          | 170       |             |            |        |
| 1920Q2    | 1919Q3   | 3         | 365         | 362        | 199       |             |            |        |
| 1928Q3    | 1927Q1   | 6         | 36          | 11         | 33        |             |            |        |
| 1931Q2    | 1929Q1   | 9         | 17          | 9          | 11        |             |            |        |
| 1938Q4    | 1933Q2   | 22        | 39          | 17         | 30        |             |            |        |
| 1943Q3    | 1940Q4   | 11        | 41          | 30         | 19        |             |            |        |
| 1945Q3    | 1944Q4   | 3         | 19          | 16         | 8         |             |            |        |
| 1947Q1    | 1946Q2   | 3         | 9           | 6          | 6         |             |            |        |
| 1952Q1    | 1949Q2   | 11        | 23          | 12         | 20        |             |            |        |
| 1954Q2    | 1953Q1   | 5         | 20          | 15         | 9         |             |            |        |
| 1957Q3    | 1955Q3   | 8         | 18          | 10         | 13        |             |            |        |
| 1961Q4    | 1959Q1   | 11        | 25          | 14         | 17        |             |            |        |
| 1965Q3    | 1963Q4   | 8         | 26          | 18         | 15        |             |            |        |
| 1967Q2    | 1966Q4   | 4         | 15          | 11         | 7         |             |            |        |
| 1970Q3    | 1969Q2   | 5         | 17          | 12         | 13        |             |            |        |
| 1974Q2    | 1971Q4   | 10        | 20          | 10         | 15        |             |            |        |
| 1976Q3    | 1975Q2   | 5         | 19          | 14         | 9         |             |            |        |
| 1979Q2    | 1977Q4   | 6         | 16          | 10         | 11        |             |            |        |
| 1981Q4    | 1980Q2   | 6         | 16          | 10         | 10        |             |            |        |
| 1984Q1    | 1983Q1   | 4         | 15          | 11         | 9         |             |            |        |
| 1986Q3    | 1985Q3   | 4         | 14          | 10         | 10        |             |            |        |
| 1988Q3    | 1987Q2   | 5         | 12          | 7          | 8         |             |            |        |
| 1990Q2    | 1989Q2   | 4         | 12          | 8          | 7         |             |            |        |
| 1992Q2    | 1991Q2   | 4         | 12          | 8          | 8         |             |            |        |
| 1994Q4    | 1993Q3   | 5         | 14          | 9          | 10        |             |            |        |
| 2000Q1    | 1996Q3   | 14        | 26          | 12         | 21        |             |            |        |
| 2002Q2    | 2001Q2   | 4         | 23          | 19         | 9         |             |            |        |
| 2004Q4    | 2003Q3   | 5         | 14          | 9          | 10        |             |            |        |
| 2007Q3    | 2006Q2   | 5         | 16          | 11         | 11        |             |            |        |
| 2009Q1    | 2008Q2   | 3         | 11          | 8          | 6         |             |            |        |
| 2011Q4    | 2010Q2   | 6         | 14          | 8          | 11        |             |            |        |
| 2015Q1    | 2013Q2   | 7         | 19          | 12         | 13        |             |            |        |
| 2017Q3    | 2016Q3   | 4         | 17          | 13         | 10        |             |            |        |

Duration
(in quarters)
Expansion 10.9
Contraction 7.79

Amplitudes (in %)
Expansion 17.1
Contraction -11.7

Cumulation (in %)
Expansion 199.7
Contraction -102.3

Excess (in %)
The mean duration of expansion is 10.9 quarters, and the contraction phase is 7.79 quarters. The standard deviation for the contraction phase is 23.5 and 27.3 for expansion. The most prolonged recession lasted 196 quarters and the longest expansion 162 quarters after 1829Q1. The expansion phase is shorter to contraction, not following general asymmetric dynamics as in business cycles. Upswing (expansionary phase) displays negative duration dependence with mean duration 10.9 to 27.3 standard deviations. Contraction episodes show a mean duration of 7.79 to 23.5 standard deviations. Both expansion and contraction phases in hydro energy consumption display negative duration dependence (mean duration > standard deviation). That suggests both phases show a higher probability to continue in time (persistence). Average cumulative losses for contraction are -102.3%, and gains during expansion are 199.7%. Cumulative losses in the contraction phase are significantly lower than gains. The highest expansion amplitude is 17.1%, and contraction -11.7%. We observe a considerably larger depth of the expansion phase. Positive divergence (318.2%) during expansion point to rapid recovery from the start and (-280%) swift decline at the beginning of the contraction period.

Table 4 presents identified turning points for nuclear energy 1956-2018 (nuclear energy cycle).

| Peak     | Trough    | Duration (in quarters) | Expansion Cycle |
|----------|-----------|------------------------|-----------------|
| 1957Q3   | 1958Q2 3  | 8.53                   | Expansion 318.2 |
| 1969Q2   | 1970Q3 5  | 44                     | Contraction -280 |
| 1972Q2   | 1973Q2 4  | 7                      | Source: Authors' own research |
| 1974Q3   | 1975Q3 4  | 5                      |                |
| 1977Q2   | 1978Q3 5  | 7                      |                |
| 1979Q3   | 1980Q4 5  | 4                      |                |
| 1985Q2   | 1986Q4 6  | 18                     |                |
| 1989Q2   | 1990Q3 5  | 10                     |                |
| 1993Q3   | 1994Q4 5  | 12                     |                |
| 1996Q3   | 1997Q2 3  | 7                      |                |
| 1998Q3   | 2000Q3 8  | 5                      |                |
| 2001Q3   | 2002Q3 4  | 4                      |                |
| 2003Q1   | 2004Q3 6  | 2                      |                |
| 2005Q2   | 2008Q2 12 | 3                      |                |
| 2009Q3   | 2010Q3 4  | 5                      |                |
| 2011Q3   | 2012Q3 4  | 4                      |                |
| 2013Q2   | 2014Q3 5  | 3                      |                |
| 2015Q4   | 5         | 10                     |                |

Duration (in quarters)
Expansion 8.53
Contraction 5.18

Amplitudes (in %)
Expansion 44.7
Contraction -17.1

Cumulation (in %)
Expansion 948.9
Contraction -52.8

Excess (in %)
Expansion 373.9
Contraction 98.5

Source: Authors' own research
The average duration of expansion is 8.53 quarters, and the contraction phase is 5.18 quarters. The standard deviation for the contraction phase is 2.12 and 9.95 for the expansion phase. The most prolonged recession lasted 12 quarters and the longest expansion 44 quarters after 1958Q2. The expansion phase is longer than the contraction and follows the general asymmetric dynamics of business cycles. The upswing (expansion phase) shows a negative duration dependence with a mean duration of 8.53 to 9.95 standard deviations. The average (positive) duration dependence of contraction ranges from average duration 5.18 to 2.12 standard deviations (Figure 6).

![Fig. 6. Turning Points in the UK Nuclear Energy Consumption, 1700-2018 (nuclear cycles)](image)

Source: Authors' own research

The expansion phase of nuclear energy consumption has a negative duration dependence (mean duration > standard deviation). The nuclear energy cycle contraction phase displays positive duration dependence. This suggests expansion phase shows persistence, nature, and contraction non-persistent. The average cumulative losses for contraction are -52.8%, and gains during expansion 948.9%. The cumulative losses in the contraction phase are significantly lower than the gains. The highest amplitude of expansion is 44.7%, and contraction -17.1%. We observe a much greater depth of the expansion phase. Positive divergences (373.9%) during expansion indicate a rapid recovery from the beginning and (-98.5) a rapid decline at the beginning of the contraction phase.

| Tab. 5. Turning Points and Oil Cycles in the UK from 1700 to 2018 |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| **REFERENCE DATES** | **DURATIONS IN QUARTERS** | **REFERENCE DATES** | **DURATIONS IN QUARTERS** |
| Peak | Trough | Contraction Peak to Trough | Expansion Previous Trough to this Peak | Expansion Trough from previous Trough | Cycle Peak From previous Peak |
| 1871Q3 | 1870Q3 | 4 | 15 | 7 | 11 |
| 1874Q2 | 1872Q2 | 8 | 20 | 12 | 12 |
| 1877Q2 | 1875Q2 | 8 | 17 | 12 | 9 |
| 1879Q3 | 1878Q2 | 5 | 13 | 8 | 8 |
| 1881Q3 | 1880Q2 | 4 | 12 | 8 | 7 |
| 1883Q2 | 1882Q2 | 4 | 12 | 8 | 7 |
| 1885Q4 | 1884Q2 | 6 | 14 | 8 | 8 |
| 1889Q3 | 1886Q3 | 12 | 14 | 9 | 15 |
| 1891Q3 | 1890Q1 | 6 | 20 | 14 | 8 |
| 1896Q2 | 1892Q2 | 16 | 25 | 9 | 19 |
| 1898Q3 | 1897Q2 | 5 | 25 | 20 | 9 |
| 1902Q3 | 1899Q3 | 12 | 21 | 9 | 16 |
| 1904Q4 | 1903Q2 | 6 | 21 | 15 | 9 |
| 1906Q3 | 1905Q4 | 3 | 13 | 10 | 7 |
| 1909Q2 | 1907Q1 | 9 | 14 | 5 | 11 |
The minimum oil cycle length is five quarters with a maximum length of fifty-five quarters (Table 5). The shortest cycle period was from 1905Q4 to 1907Q1 and the longest from 1957Q2 to 1971Q1. The average duration of expansion is 10.1 quarters, with average contraction lasting 5.6 quarters. Oil cycle exhibit a long expansion phase and shorter contractionary regime. The highest expansion amplitude measures 390%, while contraction amplitude is -17%, with expansion amplitude significantly higher than the contraction one (asymmetric oil cycles). During the expansionary regime, cumulated gain in oil consumption amounts to 329% compared to cumulated losses -57% (Figure 7).
Cycles in bioenergy consumption (Table 6) show more symmetric dynamics compared to the classical cycle. The average duration of the contraction phase (14.9 quarters) is close to the expansion phase (13.9 quarters). The average amplitude data indicate an average decline in bioenergy consumption during the contraction phase equals -9.3%. The average rise during the expansion phase in bioenergy consumption is 14.6%. The loss contracted during the drop in bioenergy consumption (-244.1%) is partly compensated by the rise in consumption during an expansion (171.9%). High positive divergences (excess in the expansion of 237.9%) indicate a rapid rebound in the early stages of expansion. In the early stages of a downswing, an excess measure (positive divergence 436.9%) suggests a sluggish decline in bioenergy consumption during the contraction phase.

**Fig. 7. Turning Points in the UK Oil Consumption, 1700-2018 (oil cycles)**

Source: Authors’ own research

| REFERENCE DATES | DURATIONS IN QUARTERS |
|-----------------|------------------------|
| Peak            | Trough                 | Contraction  | Expansion | Peak to Trough | Trough to this Peak | Trough from previous Trough | Cycle | Peak From previous Peak |
| 1702Q2          | 1701Q3                 | 3            |           |               | 8                   | 8                          | 8     |
| 1704Q2          | 1703Q3                 | 3            | 11        | 8             | 17                  | 17                         | 8     |
| 1706Q2          | 1705Q3                 | 3            | 11        | 8             | 6                   | 6                          | 8     |
| 1710Q3          | 1709Q4                 | 3            | 20        | 17            | 18                  | 18                         | 8     |
| 1712Q1          | 1711Q2                 | 3            | 9         | 6             | 16                  | 16                         | 8     |
| 1716Q3          | 1715Q2                 | 5            | 21        | 16            | 18                  | 18                         | 8     |
| 1718Q3          | 1717Q2                 | 5            | 13        | 8             | 8                   | 8                          | 7     |
| 1720Q2          | 1719Q3                 | 3            | 12        | 9             | 7                   | 7                          | 6     |
| 1765Q4          | 1750Q2                 | 62           | 185       | 123           | 182                 | 182                        | 182   |
| 1771Q3          | 1766Q2                 | 21           | 85        | 64            | 11                  | 23                         | 11    |
| 1774Q2          | 1773Q3                 | 3            | 32        | 29            | 11                  | 11                         | 11    |
| 1777Q1          | 1775Q4                 | 5            | 14        | 9             | 11                  | 11                         | 11    |
| 1813Q1          | 1800Q2                 | 51           | 149       | 98            | 144                 | 144                        | 144   |
| 1841Q1          | 1830Q4                 | 41           | 163       | 122           | 112                 | 112                        | 112   |
| 1846Q4          | 1842Q2                 | 18           | 64        | 46            | 23                  | 23                         | 23    |
| 1854Q3          | 1847Q2                 | 29           | 49        | 20            | 31                  | 31                         | 31    |
| 1857Q2          | 1855Q3                 | 7            | 40        | 33            | 11                  | 11                         | 11    |
| 1860Q4          | 1858Q3                 | 9            | 21        | 12            | 14                  | 14                         | 14    |
| Year | Quarter | Expansion | Contraction | Amplitudes | Cumulation | Excess |
|------|---------|-----------|-------------|------------|------------|--------|
| 1873 | Q3      | 1861Q4    | 47          | 60         | 13         | 51     |
| 1875 | Q3      | 1874Q2    | 5           | 55         | 50         | 8      |
| 1877 | Q3      | 1861Q4    | 4           | 13         | 9          | 8      |
| 1881 | Q3      | 1879Q1    | 10          | 20         | 10         | 16     |
| 1883 | Q3      | 1882Q1    | 6           | 18         | 12         | 8      |
| 1900 | Q3      | 1886Q2    | 57          | 74         | 17         | 68     |
| 1902 | Q3      | 1901Q2    | 5           | 65         | 60         | 8      |
| 1904 | Q2      | 1903Q3    | 3           | 12         | 9          | 7      |
| 1907 | Q3      | 1906Q1    | 6           | 16         | 10         | 13     |
| 1911 | Q2      | 1908Q4    | 10          | 21         | 11         | 15     |
| 1917 | Q1      | 1914Q2    | 11          | 33         | 22         | 23     |
| 1920 | Q2      | 1919Q1    | 5           | 24         | 19         | 13     |
| 1922 | Q4      | 1921Q3    | 5           | 15         | 10         | 10     |
| 1925 | Q1      | 1923Q2    | 7           | 14         | 7          | 9      |
| 1927 | Q3      | 1926Q2    | 5           | 17         | 12         | 10     |
| 1929 | Q3      | 1928Q3    | 4           | 13         | 9          | 8      |
| 1937 | Q2      | 1931Q4    | 22          | 35         | 13         | 31     |
| 1941 | Q1      | 1938Q3    | 10          | 37         | 27         | 15     |
| 1943 | Q2      | 1942Q4    | 2           | 19         | 17         | 9      |
| 1945 | Q3      | 1944Q4    | 3           | 11         | 8          | 9      |
| 1953 | Q3      | 1948Q3    | 20          | 35         | 15         | 32     |
| 1990 | Q4      | 1989Q1    | 7           | 169        | 162        | 149    |
| 1994 | Q4      | 1991Q2    | 14          | 23         | 9          | 16     |
| 2006 | Q1      | 1995Q2    | 43          | 59         | 16         | 45     |
| 2010 | Q4      | 2007Q1    | 15          | 62         | 47         | 19     |
| 2011 | Q2      |            |             |            |            | 17     |

**Duration (in quarters)**
- Expansion: 13.9
- Contraction: 14.9

**Amplitudes (in %)**
- Expansion: 14.6
- Contraction: -9.3

**Cumulation (in %)**
- Expansion: 171.9
- Contraction: -244.1

**Excess (in %)**
- Expansion: 237.9
- Contraction: 439.6

Source: Authors' own research

Our study separates 38 peaks and 38 troughs in the bioenergy consumption with a standard deviation for the contraction phase of 30.9 and 16.9 for expansion (Table 5).
Fig. 8. Turning Points in the UK Bioenergy Consumption, 1700-2018 (bioenergy cycles)

Source: Authors' own research

Tab. 7. Turning Points and Wind Energy Cycles in the UK from 1700 to 2018

| REFERENCE DATES | DURATIONS IN QUARTERS |
|-----------------|------------------------|
| Peak | Trough | Contraction | Expansion | Cycle |
| Peak to Trough | Previous Trough to this Peak | Trough from Previous Trough | Peak from Previous Peak |
| 1700Q4 | 1702Q4 | 8 | 364 | 376 | 372 |
| 1793Q4 | 1796Q4 | 12 | 36 | 40 | 48 |
| 1805Q4 | 1806Q4 | 4 | 40 | 44 | 44 |
| 1816Q4 | 1817Q4 | 4 | 4 | 40 | 8 |
| 1818Q4 | 1827Q4 | 36 | 4 | 40 | 8 |
| 1828Q4 | 1830Q4 | 8 | 4 | 12 | 40 |
| 1842Q4 | 1844Q4 | 8 | 48 | 56 | 56 |
| 1868Q4 | 1873Q4 | 20 | 96 | 116 | 104 |
| 1876Q4 | 1922Q4 | 184 | 12 | 196 | 32 |
| 1923Q4 | 1938Q4 | 60 | 4 | 64 | 188 |
| 1939Q4 | 1962Q4 | 92 | 4 | 96 | 64 |
| 1963Q4 | 1966Q4 | 12 | 4 | 16 | 96 |
| 1968Q4 | 1973Q4 | 20 | 8 | 28 | 20 |
| 1974Q4 | 1983Q4 | 36 | 4 | 40 | 24 |
| 2018Q2 | | | 138 | 174 |

Duration (in quarters)
Expansion 54.7
Contraction 36

Amplitudes (in %)
Expansion 106
Contraction -79

Cumulation (in %)
Expansion 7937
Synchronisation of business and energy cycles

The summary of phase amplitudes, cumulated movements, and excessive cumulated movements within business cycle phases provides more information on UK business cycle characteristics (Figure 9). The maximum phase-amplitude or depth of the recorded cycle phases is recorded during the last and longest expansion and reaches a level of 31.4 percent. The recessionary period between 1819 to 1891 has the most considerable contraction amplitude of -7.5 percent. The average amplitude of an expansion is 23.9 percent higher than the amplitude of a contraction, which indicates an asymmetry between expansions and contractions. The shape of the recognised business cycle phases can be drawn from cumulated and excessive cumulated movements. The evidence presented by cumulated movement indicators suggests significant cumulated gains in output during expansions compared to the level before the turning point. Total losses recorded during contractions are much lower but not insignificant. These findings are reflected in the average cumulated movement values, 2177 percent for expansions and -56 percent for contractions, respectively. Finally, the excess cumulated movements estimated provide further information on the shape of the expansions and contractions that appear mixed. The significant positive excess (2082%) measures suggest the actual cumulative movements and actual gain is lower in the expansion phase. During contraction, positive excess measures (4069%) suggest that the output loss during the recession is much larger. Positive divergence in expansion points to rapid output recovery from the start of the expansion phase and slow decline during contraction (Table 8).

In the UK, the average duration of expansion is 52.1 quarters, while contractionary regimes average 8.80 quarters. This is in line with the internationally recognised business cycle characteristic of asymmetry between expansions and contractions, as shown by the much longer duration of expansionary regimes than contractionary regimes. The predicted duration of expansions and contractions is also well separated in terms of standard deviations. In addition, the evidence suggests the longest expansion lasted 65 quarters and was terminated at the beginning of the recession of 2008. Historical data show the deepest recessions lasted six quarters. Simultaneously, the most recent full-cycle recorded is the longest full-cycle measured from peak to peak, lasting 72 quarters from 1990Q1 to 2008Q1.

| Peak | Trough | Contraction | Expansion | Cycle |
|------|--------|-------------|-----------|-------|
| Peak to Trough | Previous Trough to this Peak | Trough from Previous Trough | Peak from Previous Peak |
| 1701Q4 | 4 | 16 | 12 | 12 |
| 1704Q4 | 1703Q2 | 4 | 16 | 12 | 12 |
| 1708Q2 | 1706Q3 | 8 | 20 | 12 | 16 |
| 1711Q4 | 1710Q4 | 40 | 56 | 16 | 48 |
| 1717Q4 | 1729Q4 | 28 | 104 | 76 | 64 |
| 1738Q4 | 1737Q4 | 4 | 36 | 32 | 8 |
| 1742Q4 | 1740Q4 | 8 | 20 | 12 | 16 |
| 1807Q4 | 1744Q4 | 252 | 268 | 16 | 260 |
| 1815Q4 | 1808Q4 | 28 | 284 | 256 | 32 |
| 1817Q4 | 1816Q4 | 4 | 36 | 32 | 8 |
| 1891Q4 | 1819Q4 | 288 | 300 | 12 | 296 |
| 1899Q4 | 1892Q4 | 28 | 320 | 292 | 32 |
| 1902Q4 | 1900Q4 | 8 | 40 | 32 | 12 |
| 1907Q4 | 1903Q4 | 16 | 28 | 12 | 20 |
| 1916Q4 | 1908Q4 | 32 | 52 | 20 | 36 |
| 1929Q4 | 1921Q4 | 32 | 84 | 52 | 52 |
| 1943Q4 | 1931Q4 | 48 | 88 | 40 | 56 |
| 1979Q4 | 1947Q4 | 128 | 192 | 64 | 144 |
| 1990Q4 | 1981Q4 | 36 | 172 | 136 | 44 |
After dissecting the UK business cycles from 1700 to 2018, we check for synchronisation between different energy type cycles and identified business cycles. Using Harding and Pagan (2002) concordance index, we derive the concordance index between various energy cycles and business cycles in the UK during the observed period (Table 9).

| Business cycle | Concordance Index |
|----------------|-------------------|
| Coal           | 0.62              |
| Gas            | 0.67              |
| Hydro          | 0.54              |
| Nuclear        | 0.58              |
| Oil            | 0.61              |
| Bioenergy      | 0.58              |
| Wind           | 0.52              |
| Solar          | 0.76              |
| Thermal        | 0.53              |

Source: Authors' own research
We see energy cycles and business cycles in the UK share a pattern, with more than 50% of the time observed moving together (various energy cycles and business cycles coinciding at the same phase of the cycle). Since all the index values are above 0.50, we conclude there is a systematic relationship in the dynamics of different energy cycles and business cycles in the UK. The relationship is particularly strong between solar energy and business cycles. The fact is not surprising since the majority of green investments is going into solar energy development. Fossil fuels still show a significant link with business cycles with coal (0.62) and gas (0.67) concordance index. Oil (0.61) is slowly losing importance, but it is still more closely related to business cycles than alternative sources of energy (Hydro 0.54, Nuclear 0.58, Bioenergy 0.58, Wind 0.52).

**Discussion**

Our study is novel research in the field of energy economics estimating the link between energy and business cycles. Previous studies generally look at the link between energy consumption/use and economic growth with inconclusive findings. Our study has three important findings. Primary energy consumption/use exhibits cyclical behaviour with phases like the business cycles. Cyclical patterns and phase dynamics differ across primary energy sources. Here we provide empirical evidence on the existence of turning points (phases) in energy consumption. The next finding points to the existence of a systematic relationship between energy and business cycles using the concordance index (Harding & Pagan, 2002). Empirical results show fossil fuels sources have a significant systematic relationship with GDP dynamics in the UK. It is interesting to observe that the strength of the relationship is for all fossil fuels quite close (concordance indexes; coal 0.62, gas 0.67, oil 0.61). We see fossil fuels consumption and GDP move closely together supporting findings of (Coers & Sanders, 2013; Mohammadi & Parvaresh, 2014; Nachane et al., 1988; Lee & Chang, 2008; Narayan & Smyth, 2008; Apergis & Payne, 2009a, 2009b, 2009c; Valadkhani & Nguyen, 2019; Ozturk & Acaravci, 2013).

Our third conclusion, backed up by empirical evidence here, proves that primary energy consumption/use is a driver of economic growth. Not only, but business cycles are also driven by changes in energy consumption/use (energy cycles). Thus, factors connected to energy cycles (energy prices, for example) have a strong impact on business cycles as well (Brown et al., 2003; Aminu et al., 2018; Kim & Longani, 1992; Schmidt & Zimmerman, 2012; Huynh, 2016). In fact, a strong systematically link between them exists.

Policymakers and practitioners concerned with the business cycles negative effects must pay a closer look at energy cycles. Because of data bias, econometric issues (stationarity, non-linearity, causality), the nature of the business cycles remains uncertain. Like the one we use here, turning points analysis provides results on the systematic relation between energy and business cycles. Such quantitative knowledge can be used to explain deeper the dynamics observed in the business cycle. Energy cycles, which we explore in this study for the first time in the field, supply such quantitative knowledge to clarify the business cycles’ nature.

The carbon emissions target for 2030 set globally will not be met. Limiting financial conditions for renewables across regions and countries, differences in the technological adoption rate, economy/industry structure are significant constraints for the energy transition. To get global support for energy transition from all economic agents, energy cycles and their impact on growth should be explained. Unravelling energy cycles in the literature and business is important for understanding how energy cycles affect managerial decisions and firms' performances to business cycles conception in time of environmental crisis.

The choice of data here was based on data availability and primary research scope. To search for the existence of energy cycles, we need long time series, so for this reason, we use data for UK. Also, the UK is a good case-study since it offers historical data on energy consumption/use and economic dynamics (GDP) over a long time. Future studies using panel data and cross-country samples is needed to support the idea of energy cycles. Besides the modern applied econometric approach, additional insights in energy cycles can be supplied by using different business cycles filtering methods, unobserved component analysis, turning points. In the end, we also need a comprehensive global study on the existence of a global energy cycle, potential convergence, synchronisation across countries and regions.

**Conclusion**

Literature on energy and growth link is missing research on energy cycles, like the one we present here. A design of successful macro policy demands from policymaker's quantitative knowledge on major economic forces driving the economy. Energy consumption/use is one of these major economic forces. Understanding the nature of energy cycles help us to discover the true nature of business cycles. The link is important since energy cycles move closely together with business cycles. In fact, energy cycles have a deep impact on the economy, and they drive the business cycles. Energy cycles impact on the business cycles will be significantly deeper and larger in future, with alternative energy sources (particularly solar energy) taking a head role in primary energy use. We hope to encourage future studies on energy cycles measurement and methods, synchronisation across energy and business cycles to determine the actual effect of energy on growth. We must learn the impact of energy on growth
in the past to foresee the effects alternative energy sources will have on growth in the future. Energy cycles are an empirical fact, and we must learn from them to fully understand business cycles and economic growth. Future studies should focus on more countries (this study limitation) for comparison of energy cycles duration and path. Also, energy cycles determinants using logit/probit regression can be explored using data from more countries even with smaller time horizons (data since 1960). Limitations of our study do not constrain the contribution to the field since the goal of this study was to provide empirical evidence on energy cycles for the first time (not to explore them globally).

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