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Abstract

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Keywords: Energy transitions, economic history, business history, political economy

JEL: N50, N70, Q40, Q50

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Abstract

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Introduction

The climate crisis is at the core of attention to the need for an energy transition at a scale resembling a new 'low carbon' industrial revolution. Identifying potential pathways to a low-carbon economy will be a defining challenge for the world economy for decades to come. It is argued that the low-carbon energy transition will require disruptive change in form of radical reductions in emissions and large-scale technological breakthroughs. In technological terms it involves, among other things, a transformation towards decarbonized electricity production, electrification of transport, battery technology, energy storage, smart grids and overall improved energy efficiency. But beyond exemplified technological fixes, a decarbonization of the energy system also necessitates a new architecture of the political economy that can support such a large-scale global transformation.

As energy transitions are relatively exceptional and prolonged processes, social scientists have increasingly turned their attention to historical experiences for lessons about how they might unfold in the future. The literature on historical energy transitions has grown considerable in the last three decades or so (e.g. Gales et al. 2007; Allen, 2009; Wrigely, 2010; Kander et al. 2013; Rubio & Folchi, 2012) also outside the historical disciplines with a number of books and special issues devoted to the topic (e.g. Smil, 2010, 2016; Van der Graaf et al. 2016; Sovacool, 2017). But the broader literature on energy transition debates somewhat other issues than economic and business historians traditionally do by focusing on how emerging technologies, policies, and societal attitudes interact with the existing energy regime and the broader landscape factors (Geels, 2002, 2014). Moreover, the term energy transition typically refers to the global shift from traditional fossil fuel-based energy sources, driven by concerns about climate change, energy security and the environmental impact of traditional energy sources.

The historical evolution of energy regimes and transitions offers a vantage point – it enables us to understand that as we move forward, a new energy regime will likely weave into the extant fabric rather than overhaul it entirely. An essential takeaway from the study of historical transitions is also the pattern they follow: it is never about the complete discontinuation of one energy source in favor of another. Instead, new energy sources find their own space within the prevailing energy framework, complementing rather than replacing the existing sources. At the same time, with the current urgency driven by climate change considerations, the nature and pace of these transitions will need to differ from those of the past. Against this backdrop, the paper examines how the present political economy and barriers for energy transitions compare with past energy transitions.

State of art

Defining and measuring energy transitions

While there is no formal or generally accepted hierarchy of meaning of "energy transition", the concept is often used to describe the change in the composition (structure) of *primary* energy supply, which involves the gradual shift from a specific pattern of energy provision to a new state of an energy system (Smil, 2017). Primary energy is directly embodied in natural resources, prior to its being converted or transformed for use, such as coal, crude oil, uranium, wind and hydro. Secondary energy refers to energy carriers, such as electricity and petrol, which has been transformed from primary energy sources. Electricity can in other words be transformed from various primary energy sources, such as coal, oil, natural gas and wind (e.g. US IEA, 2021). Some economic historians such as Kander et al. (2013) uses an economic definition of primary sources of energy, and ends up counting for food; fodder for draft animals; firewood; water and wind power, or water and wind; coal; oil and natural gas; and electricity from nuclear power or hydro power, or wind and water, or geothermal sources as the *primary sources of energy*. They refer to secondary energy carriers as those that have been subject to extensive transformation (2013, p 20).

Competing definitions of energy transitions exists. Some define energy transitions as the time that elapses between the introduction of a new primary energy source or 'prime mover', and its rise to claiming a substantial share of the overall market, more precisely 25 percent (Smil, 2010). According to Vaclav Smil (2010) energy transitions are prolonged processes that take decades to accomplish, and the greater the scale of prevailing uses and conversions, the longer the substitutions will take. If fast transitions occur, they are, according to Smil's observations anomalies, limited to countries with very small populations or unique contextual factors (Smil, 2010: 141-2). Fouquet and Pearson (2012) suggested that the switch from an economic system dependent on one or a series of energy sources and technologies to another, defines the transition. Echoing the analysis of Smil (2010; 2016) Fouquet and Pearson also define energy transitions as lengthy events. Fouquet (2016) found that the fastest historical sector specific energy transition took 30 years, while full energy transitions, involving all sectors and services takes several decades, even centuries.

The transition to coal has been regarded as the first major energy transition in human history, which marks the beginning of a fossil fuel energy regime (McNeill, 2000). As argued in the extensive work on the European energy history by Kander et al (2013), the transition to fossil fuels was not the end, but only the beginning of modern energy transitions. Indeed, they argue that the history of transitions has been a story about a history of *substitution*s, with "societies shifting the demand between, for example, wood and coal or coal and natural gas according to price" (Kander et al. 2013, 8). The environmental historians McNeill and Engelke (2016) have, from an environmental point of view, stressed the emergence of one big fossil energy regime, that have contained several phases; first the introduction of coal, then oil followed by natural gas. While coal outstripped biomass as the world's primary fuel by 1890, oil replaced coal as the worlds primary fuel only in 1965 (McNeill and Engelke, 2016, 9).

Smil (2014) has further stressed though that the overall transition to coal was slow, and so was the transition to oil and natural gas (50-60 years). Coal began to supply more than 5 percent of the world energy around 1840, but still only supplied half of the energy demand by 1900. Outside England, the tipping point occurred 1885 in the US, 1875 in France, 1901 in Japan and only in 1930 in the USSR, 1965 in China and the late 1970s in India (Smil, 2014, 55-56). The slow pace in transitions is according to Smil due to the enormous investments and infrastructures needed worldwide for any new energy source to capture a large share of the market, which requires 50-75 years. But as further argued by Sovacool (2017) the 'speed' or ´scale´ at which energy transitions occur, might have less to do with what actually happened, and more to do with what or when one counts. If the coal transition took about 80 years to reach a 25 percent share in the US (as suggested by Smil), one can also look at the years from 1900 to 1925 when oil grew from 2.4 percent of the share to 24 percent, and then the transition looks "quick" (Sovacool, 2017, 30).

The Industrial Revolution and the coal transition

Economic historians have to large extent been concerned with the so-called coal transition. As such, the industrial revolution and the rise of modern economic growth has even been interpreted as an energy transition (Sieferle 1982). During this transformative period, as described by Anthony Wrigley (2010), England underwent a significant evolution, transitioning from a dependence on organic energy — predominantly characterized by reliance on biomass such as wood and manual labor — to a burgeoning reliance on fossil energy, particularly coal. As argued in the seminal work of Kenneth Pomeranz (2000), this shift from organic biofuels to coal marked a revolutionary change in the British energy situation. Coal not only provided a far more abundant energy resource, but it also effectively bypassed the limitations imposed by land availability, which had constrained biomass-based energy production. Reinforcing this narrative, Robert Allen (2009) posits that coal's ascendance as a primary energy resource catalyzed the process of mechanization, a hallmark of the Industrial Revolution. John U. Nef (1932) offered early on a perspective that emphasizes the peculiarities of British coal's rise. In Nef's view, the transition in Britain was not merely a response to declining woodland or increasing energy needs; it was deeply influenced by technological, economic, and institutional variables.

At the same time, energy prices and labour costs, possible timber shortages and the evolution of institutional changes, including property rights, have been discussed in relation to the coal transition. One example is Allen's (2009) hypothesis that the British combination of high wages and low fuel prices provoked the industrial revolution as a means to save on labour costs. Yet, while Wrigley (2010, p. 23) regarded the coal transition as 'a necessary condition for the industrial revolution', Joel Mokyr (2009, pp. 101–2) stated that 'The Industrial Revolution did not absolutely "need" steam . . . nor was steam power absolutely dependent on coal'. Empirically, Gregory Clark and David Jacks (2007) used a counterfactual methodology to show that the energy demand of the Industrial revolution hypothetically could have been met by imports. Alan Fernihough and Kevin H. O'Rourke (2021) have, however, demonstrated a clear relationship between proximity to coal and city growth after 1750, consistent with the accounts of Wrigley (2010) and several other economic historians. Although Britain holds a special position concerning the coal transition, there are several studies on other countries of which historical energy transitions have been elaborated.

This nuance in transition drivers is evident when contrasting Britain's experience with that of other European nations. The Industrial Revolution provided a prototype, but nations did not merely mimic Britain's path. As Kunnas and Myllentaus (2009) have argued, Finland is the only historical example of a country that experienced a bio-energy based industrialization. Instead, each country underwent unique transformations based on its socio-political context and resource availability. Astrid Kander et al. (2014) aptly describes these differential trajectories by analyzing European industrialization between 1870 and 1935. The outcomes varied, with certain countries rapidly industrializing, while others showed more staggered progress. This divergence was particularly evident in energy intensity and trade dynamics. But in sum, the Industrial Revolution of the late 18th and early 19th centuries stands as a testament to how closely knit energy sources became to economic progress.

It has been noted that the Industrial Revolution and the transition to coal not only created modern economic growth, but also laid the foundation of the British hegemony in geopolitics. Charles A.S. Hall and Kent Klitgaard (2018) argued from a perspective of biophysical economics that virtually all major institutions characterizing industrial capitalism are the result of fossil fuels. Fossil fuels not only enabled economies of scale, long-distance trade, and productivity growth but also played a fundamental role in shaping institutions. The ascent of coal and later oil was not merely about replacing wood or increasing productivity; it was enabling and shaping the course of global capitalism. In his collection of essays, Ben Fine (1990) examined the historical political economy of the British coal industry, including the structure of the industry; the system of property rights in which it developed; public ownership and denationalization in the 1980s. Other central themes in the political economy of coal includes market power and labour conflicts (i.e. Rössel 2016), as well as war and conflict (i.e. Hardach 1980, 27-28; Brüggemeier 2022). Also major institutional changes, such as the creation of the European Coal and Steel Community (Milward 1984; Eichengreen 2006; Berger and Ritschl (1995) and, more recently, the growing European dependence on Russian gas (Högselius 2013) should be mentioned. In short, a dense institutional and socio-political web, with a multitude of interest groups, arose from the coal transition.

Transition to oil

Business historian Alfred D. Chandler's (1980) observations underline this interaction between not only coal's but also oil's proliferation and institutional reconfigurations. Institutions did not merely react to energy transitions; they actively shaped them. This mutual influence of institutions and energy sources was pivotal in determining the pace and nature of economic development across regions (Chandler, 1980). An astute observation arises when considering role of coal and later oil in fostering capitalism. Its ascension was not just about replacing wood or increasing productivity; it was a crucial cog in the machinery of global capitalism (see also Angus, 2016). This notion challenged early on the conventional wisdom of energy transitions being merely about technological or resource switches. Instead, they intertwine with broader political economy paradigms. Chandler's observations underline the active role of institutions in shaping energy transitions, particularly evident during the Second Industrial Revolution. As modern industry organization expanded enterprises such as Standard Oil, organized mechanisms became essential for adeptly handling energy distribution and utilization. At the same time, other industrial organizations, such as Ford, created new demand for end use of energy. Institutions were pivotal in ensuring that new energy sources integrated with the prevailing infrastructure (Chandler, 1980).

As we have seen, many economic historians have focused on the dynamics behind the coal transition, but from a political economy point of view, oil was more formative implications for industrialization, transportation, geopolitics and international relations in the twentieth century. A comprehensive historical work on this issue is Daniel Yergin's (1991) work on history of the oil industry and its impact on global politics and economics. His book underscores the economic significance of oil, not only as a source of energy but also as a commodity that has shaped economies, industries, and financial markets. However, along with continuing debate about petroleum resource depletion, the volatile geopolitics of oil and gas, there has been a sharpening policy priority on energy transition since the late 1980s. Chief among the drivers has been the widely perceived societal threat of damage from climate change caused by human-induced greenhouse gas emissions from fossil fuel (Pearson, 2018). This development is mirrored in Yergin's recent book *The new map. Energy, Climate and the Clash of Nations* (2020), in which he explores the implications of the changing energy landscape on global power dynamics, highlighting how countries are jockeying for influence in the quest for energy resources and the race to address climate change.

Cognizant of these historical transitions mentioned above, it becomes clear that energy evolutions are intertwined with the broader fabric of economic, social, and political developments, including power relations. Several transition scholars have pointed out that 'obstacles' to the contemporary energy transition arises more from social and political contexts, resistance by incumbent interests, rather than from physical or technological obduracies (Bridge & Gailing, 2020, 1039, Stirling, 2014, 15; Foquet, 2016, 9, Yergin, 2020). Here lies vested interest in existing energy regimes, which can be defined as 'historical blocs' (Newell, 2019, 28, Geels, 2014) or 'carbon lock-in' (Unruh, 2000). Here lies perhaps the most challenging barrier for a future transition. Scholars have observed for a long time that industrial economies have been locked into fossil fuel-based energy systems through a process of technological and institutional co-evolution driven by path-dependent increasing returns to scale (Chandler, 1980; Unruh, 2000; Seto et al., 2016).

The Political Economy of Energy Transitions

The political economy of energy transitions thus involves a complex chemistry of political and economic factors, which in turn influence the shift from one energy system to another. Shifting energy prices and energy transitions as such, have had significant implications for political power, economic structures, and social dynamics. These conflicts arise due to the redistribution of power, economic interests, and competing policy priorities associated with changes in the energy landscape. Nations as well as companies have both been navigating within these landscapes, as well as shaping them. This is mirrored clearly by the most critical events in the history of the twentieth century besides the world wars; the OPEC oil embargos in the 1970s, which shook the world economy and power balances and rendered a comprehensive energy policy in most countries.

Drawing on the works by Van de Graaf et al. (2019) and Yergin (2020), we summarize below key areas and shifts in the international political economy and energy regimes since the Industrial Revolution. Although it is not possible here to discuss and deepen every period in each box in Figure 1, it provides a stylized framework for how to comprehend the political economy of energy regimes to present day. As we suggest, the Covid-19 crisis and Russia's conflict with Ukraine mark the onset of a new era in which technologically advanced superpowers (EU, China, USA) are spearheading the transition to a low-carbon future. The primary drivers for this shift include intense competition for fourth industrial revolution technologies, artificial intelligence (AI), and electric low-emission vehicles (ELV). The interplay between strategic industries, particularly in sectors like car manufacturing, and state entities signals a shift towards a new era of technological superpower managerialism. Simultaneously, there is a de-emphasis on both neoliberal policy tools and global negotiations, as technologically advanced superpowers proactively assume a central role in orchestrating the transformative process. In this interpretation, the Paris Agreement in 2015 signifies the conclusion of an era rather than its commencement. According to this perspective, the state-capitalist era is viewed as a concluding sub-phase within the broader liberal era, and this overarching epoch is suggested to have concluded around the year 2020.

Figure 1. Key eras and shifts in International Political Economy and Global Energy Regimes

Eras	Global energy shifts	Patterns of energy governance
1840-1914 **Imperial liberalism and globalisation** Geopolitics: British Hegemony *Global South*: Imperialism and colonialism Finance: gold standard and free trade Globalisation	Transition from biomass (bio energy regime) to coal. Oil stroked in Pennsylvania 1859. Oil used for lightning purposes (substitute for whale oil). Development of local industries for town gas (manufactured from coal).	**Birth of oil industry in the US (1859-1900)** Intense competition and rivalry in US oil industry. Standard oil (US). British Petroleum and Royal Dutch Shell. Rivalry in Europe on coal resources (Germany, France)
1914-1945 **Mercantilism, war economy and de-globalisaton** Geopolitics: lack of leadership Global South: Imperialism and colonialism Finance: Instability, competitive devaluation, autarky and war	Coal still reigns but oil rises in importance. The advent of the first mass-produced car and major oil discoveries in the Persian Gulf in the late 1920s.	**Neo-colonial order** (1900-1970). Resource nationalism Fierce competition between British, French and US companies (supported by their governments) to secure oil concessions in the Middle East. In 1928, 'seven sisters' form a cartel not to compete on market share or price.
1945-1980 **State Interventionism and socialism** Geopolitics: US-Soviet Gold war. Bipolarity. Global South: De-colonialisation Finance: Bretton Woods until 1971, then mix of dollarization and managed/flexible exchange rates	Oil overtakes coal in 1964. Town gas is steady replaced by natural gas, first in the US (pipeline construction boom) and then in Europe where gas is discovered by the Dutch, British and Norwegians. State-driven advent of nuclear industry, but enthusiasm is soon tempered.	Seven sisters deliver oil at declining real prices, fueling post-war economic growth in OECD. **OPEC revolution** (1970-1986). Rising oil demand, US oil production peaks in 1971, OPEC takes control of production and prices until 1986, when Saudi Arabia floods the oil market to regain share. The rise of national oil companies (NOCs)
1980-2008: **Liberal capitalism** Geopolitics: US hegemony, unipolarity. Global South: Dept crisis, neoliberalism. Finance: finacialisation, globalization	Oil prices generally low in late 1980s-1990s. Opening of Soviet oil and gas industry to international market. Dash for gas in UK and elsewhere. Coal use falls in 1980s and 1990s, but rebound in 2000s. Electricity use continues to grow.	**Neoliberal order** (1986-2000). Growth of spot trading and future trading, marking growing financialization of oil. Drive to liberalize and deregulate electricity and gas markets

2008- **State capitalism.** Geopolitics: rise of BRICs, multipolarity Global South: Emerging markets Finance: Regulation, regionalism, reform of global system. De-globalisation Climate Crisis	Rising demand from China and India raises commodity prices. Fracking revolution in the US unlocks vast amounts of shale oil and gas. Global drive to efficiency and low carbon energy source (wind and solar) Increased electrification	**State-capitalists order** Rising oil prices spur new era of resource nationalism Emerging economies pursue state-led form of capitalism, often conducted via NOCs. OECD still adheres to liberal form of capitalism but relies on public policy to pursue decarbonization.
2020 – Technological Superpower managerialism? Geopolitics: Escalating tensions between China and the US and EU Finance: return to high interest rates State investment in large projects Climate Emergency	Fuel price shock and due to Russia's war on Ukraine, gas for hybrid warfare triggers EU energy Transformation Covid 19 disrupts global value chains: supply side inflation New wave of technology: ELV and AI	Superpower ambition to control new technology: EU Green Deal, US: Inflationary Recovery Act, China: New ELV development plan Superpower search for low carbon strategies rather than global negotiations State managerialism replaces neoliberal ideal market conform policy tools

Sources: Modified from Van de Graaf et al. (2019) and Yergin (2020).

The rise of the fossil fuel energy regime and its political economy

The ascent of oil as a dominant energy source commenced with the discovery in Pennsylvania in 1859. But as mentioned, it was not until the mid-20th century that oil solidified its position as the largest energy source on a global scale, reaching this status in 1965. As explained by McNeill, the United States shifted to oil first, between 1910—1950, while Western Europe and Japan, which had a stronger attachment to coal, shifted to oil between 1950—1970 (McNeill, 2001, 298). The entrance of oil in the global energy system also implied massive oil transport, especially after petroleum poor European and Japanese economies converted from coal to oil. Natural gas also increased in importance, but only slowly. Before World War I, the United States was the only notable consumer of natural gas and during the Post-War II, the country saw a rapid gas extraction. The first shipment of liquid natural gas (LNG) took place in 1959 and the first methane liquefaction plant was completed in Algeria in 1964. Natural gas grew in importance from the 1960s, when its cleanness and flexibility began to justify a high price on LNG (Smil, 2017, 28).

Indeed, it was the transformative journey towards oil that first reshaped global economic structures, power relations, and geopolitical dynamics (Yergin, 1991). Oil enabled an intensified industrial drive and exponential economic growth based on *additional* fossil fuels as petroleum made its way into the energy system. The relative transition towards oil was driven by innovations related to secondary and final energy, particularly the inventions associated with the internal combustion engine and electrical equipment that required diesel or gasoline for the former and generation and transmission of electric power for the latter. As Chandler (1980) argued, the spread of managerial hierarchies and arrangements enabling vertical and horizontal integration coevolved with the vast exploitation of new sources of fossil fuels. And unlike coal, the demand for petroleum set off a world-wide search for oil and a struggle for wealth power connected to oil already by the World War I (Yergin, 1991).

In the United States, mass production, mass distributions and mass consumption co-evolved with the application of coal fired steam power and electricity and petroleum driven combustion engines. After the World War II, the increasing networks of large diameter pipelines and construction of massive crude oil tankers made it possible to trade oil at low costs (Smil, 2010). Oil became the "instrument that caused advanced industrial economies to become totally and possibly fatally addicted to fossil fuels" (Chandler, 1980, 47). One reason behind the emergence of cheap oil in the postwar era, was the discovery of giant oilfields in the 1950s and the 1960s; in Saudi Arabia, Iran, Abu Dhabi, as well is the United States, Canada, and the Soviet Union. Discoveries of oil in Algeria, Libya and Nigeria also made Africa a major new supplier, while China discovered their first gigantic oilfield in 1959 (Smil, 2017, 45). Households claimed a relatively small share of overall energy consumption in the early phase of industrialization, but with the fast growth in home appliances (refrigerators, electric stoves, washing machines) and in car ownership, the relative share of households' energy consumption increased dramatically during the first half of the twentieth century. The households became by the 1960s a leading energy-using sector in all affluent countries (Smil, 2010, 10). As the supply of oil, but also gas, became abundant, high-income countries also learned to take cheap energy for granted.

At the same time, the geopolitical implications of oil became instrumental in shaping power dynamics. Countries with vast oil reserves or strategic control over distribution gained significant political leverage, creating an intersection between the geopolitical importance of oil and the global spread of capitalism Yergin (1991). Oil's versatility, energy density, and potential for mass production made it indispensable for emerging industrial economies and modern warfare. Countries that held vast oil reserves or controlled its distribution channels gained significant political leverage. (Stanislaw & Yergin, 1993). This resulted in power dynamics that favored oil-rich nations or those with strategic control over its supply routes.

An intriguing intersection emerges when one juxtaposes the growth of oil with the spread of capitalism. Carlsnäs (1988) argues that oil played an indispensable role in maintaining national security and furthering global capitalist agendas during the Cold War. Its significance was not limited to fueling industries or vehicles; it was the lifeblood of modern capitalist economies. A reliance on oil invariably linked to a nation's economic well-being and geopolitical stance. In parallel, vested interests of powerful oil corporations and their intricate connections with political establishments have historically hindered swift energy transitions. With substantial investments in existing infrastructure for oil and gas extraction, refining, and distribution – the coal, oil and gas industry remained reluctant to disinvest from fossil fuels, although many companies started to get actively involved in research and development of wind and solar power from the 1970s (Jones, 2017, Boon, 2019).

The Power of the 'Incumbent' Energy Regime

Established energy regimes are deeply embedded in our global socio-economic fabric. This 'incumbent' energy system, characterized primarily by its reliance on fossil fuels, wields substantial power in shaping the trajectory of future energy pathways. As argued by Yergin (2020) the prevailing energy regime, which has been foundational to capitalist development since the Industrial Revolution, is resistant to change due to its entrenched interests. The fossil fuel economy has benefactors, both corporate entities and state actors, that have reaped substantial economic benefits. Consequently, these stakeholders are unlikely to relinquish their advantageous positions without significant impetus.

It's crucial to understand the magnitude of the barriers posed by this incumbent system. On the one hand, there are technological and infrastructural challenges; transitioning to new energy sources often requires significant investments in new technologies, equipment, and facilities. On the other hand, the sociopolitical challenges are even more daunting. Historical evidence suggests that the incumbents in the energy sector, backed by their political allies, have often resisted transitions, even when confronted with clear environmental and social imperatives. Thus, the co-evolution of institutional structures and energy regimes implies that institutional path-dependency constitutes a strong barrier for energy transitions (Arthur 1989, Unrah, 2002). For instance, Boon's 2019 study on the oil industry's response to the increasing urgency of decarbonization illustrates a crucial part of this resistance. Despite mounting evidence about the environmental impacts of carbon emissions, the fossil fuel industry – not the least the oil industry – has been slow or reluctant to adapt, with various factions within the industry either downplaying the need for change or outright resisting it. The historical literature on so-called climate delay strategies, which involves tactics or approaches employed by corporations, organizations, or governments to slow down or hinder the progress of climate change mitigation, has been growing fast in the recent decade (e.g (Oreskes & Convey, 2011; Franta 2022, Bonneuil et al, 2021).

Furthermore, transitions scholars such as Frank Geels (2014) have denoted the coalition of actors, institutions, and technologies that are mutually reinforcing and support a particular socio-technical regime as historical blocks. The notion of historical blocs has also been explicitly translated into analysis of energy transition inertias (Newell, 2019), where Phelan et al (2013) have used the notion of 'fossil fuel historical block' to point at the actors that systematically benefit from carbon dependent economic growths. Example actors and groupings constituting the fossil fuel historical bloc include the oil, coal and energy-intensive sectors, and governments relying on continued carbon-dependent economic growth to maintain their societal legitimacy. Bridge and Gailing (2020) emphasize the role of 'energy spaces'. They argue that the very conception of energy is often territorially bound, linking energy sources to national interests and geopolitics. This territorial conception further entrenches the position of incumbent energy sources, making transitions even more complex. In conclusion, understanding the dynamics of this incumbent system provides valuable insights to understanding why energy transitions are not happening very fast, but are blocked nor only by a complex of technical systems and path dependency, but vested interested that will not give up their positions easily.

Nuclear Power, Hydropower and Wind and Solar

The energy mixes across individual countries demonstrate differences, where some countries have been more successful than others in replacing replace fossil fuels with hydro-, nuclear-, wind-, and solar energy (Kander et. al 2013; Rubio-Varas & Muñoz-Delago) depending on factors such as natural geography, technological capabilities and differences in government policy orientations. Sweden and France are illustrating examples. Both countries shared many similarities prior to the 1970s energy crisis, such as a heavy dependency on oil.

Despite both countries undergoing an energy transition in the power sector through the development of nuclear power, Sweden also transformed the residential heating sector. This involved the establishment of biomass-fueled district heating, utilizing biomass resources (Millot et al., 2020). Additionally, Sweden pursued a substitution of oil with internal (forest) biofuels in manufacturing, most notably the pulp and paper industry (Lindmark et al., 2010). However, in accordance with Smil's perspective (Smil, 2010: 141-2), rapid transitions are typically observed as anomalies, limited to countries with very small populations or unique contextual factors.

In the broader context of wind and solar energy, Jones (2017) investigated the expansion of the global solar and wind power industry. Despite significant investments in countries such as the United States following the oil shocks in the 1970s, Jones determined that the capacity of wind and solar power remained minimal by 1980.

Oil companies accounted for 80 percent of all the solar modules sold in the United States, while US-based companies accounted for 85 percent of world sales (Jones, 2017, 331). According to Jones, public polices remained focused on supporting fossil fuels and nuclear energy, which made it impossible to build a market and raise the capital needed to finance innovation at reduced costs in the wind and solar industry. Government policies in the United States underwent a notable shift only in the 1990s. This, coupled with the declining costs of Chinese-made solar panels and the scaling of wind power, particularly notable in Denmark, catalysed a swift expansion of solar and wind power, despite from low levels (Jones, 2017).

Yergin (2020, 412) has observed that while wind and solar energy has been increasing, they are doing so atop conventional energy, which is also growing. It is important to note that fossil fuels (coal, oil, and gas) still accounted for 82 percent of the commercial global primary energy use in 2021 (see Table 2). From a global point of view, the share of hydropower, nuclear power and wind and solar power in commercial global primary energy use still only amounts to 14 percent (BP, 2022, p 3).

Table 2. *Commercial Global Primary Energy Consumption by Fuel 2021*

Type of Fuel	Percent
Oil	34
Coal	27
Natural Gas	24
Hydro Electric	6
Nuclear Energy	4
Renewables (wind and solar)	4

Source: British Petroleum Statistical Review 2022, p 3.

According to Smil (2014), a transition towards more wind and solar energy may occur more swiftly in certain nations. However, the global shift towards renewables is anticipated to progress at a measured pace, especially in light of the ongoing transition to natural gas. In Smil's analysis (2014) the transition to renewable energy will take at least 50-60 years. In rich countries, "old" renewables, like hydroelectricity, has already reached its maximum potential. Consequently, the expansion of renewable energy in these regions will predominantly stem from wind and solar power, geothermal energy, and biofuels.

The political dimensions of hydroelectric energy encompass ecological concerns related to large dams, exemplified by conflicts like the 1982 Franklin River dispute in Tasmania (Kellow 1989). Additionally, tensions with ethnic minorities, as in the Alta River conflict in Norway (Andersen et al., 1985) highlight social complexities. Moreover, the management and conflicts surrounding transboundary hydroelectric projects, like the Indus Waters Treaty of 1960 (Bhat, 2020), underscore international political considerations in the realm of hydroelectric energy.

The story of energy transitions in the 20th century would be incomplete without delving into the issue of nuclear energy. As global powers postured to harness atomic energy after World War II, the nuclear discourse became an arena of intense political, economic, and societal debates. Nuclear power promised unparalleled energy yields, and the Soviet AM-1 "peaceful atom" reactor in 1954 and the British Calder Hall plant in 1956 and marked the advent of civil and commercial nuclear power respectively (Arnold 2000; Pryde 1979). The potential link between civil nuclear programs and the proliferation of nuclear weapons prompted the establishment of the UN Atomic Energy Commission (UNAEC) in 1946. Simultaneously, the United States proposed the "Baruch Plan," advocating for the international control of all nuclear activities (Siracusa 2020).

The near nuclear disaster of Three Mile Island in 1979, the catastrophic events of Chernobyl in 1986 and Fukushima in 2011, as highlighted by Smil (2015), underlined the inherent risks of nuclear energy. These disasters triggered a global introspection on nuclear safety standards and its role in the future energy mix. Some nations began reconsidering their nuclear ambitions, leading to a paradigm shift in energy policies. Grubler (2012) reinforced this point, arguing that the challenges of transitioning to nuclear power were as much sociopolitical as they were technological.

While there have been calls for a significant expansion of nuclear power as a solution to combat global warming, the atomic age's allure has not been without reservations. Sovacool (2016) raises critical questions about the speed and efficiency of particularly the nuclear shift. While the scientific community was largely optimistic, the broader public response was a mix of anticipation and anxiety.

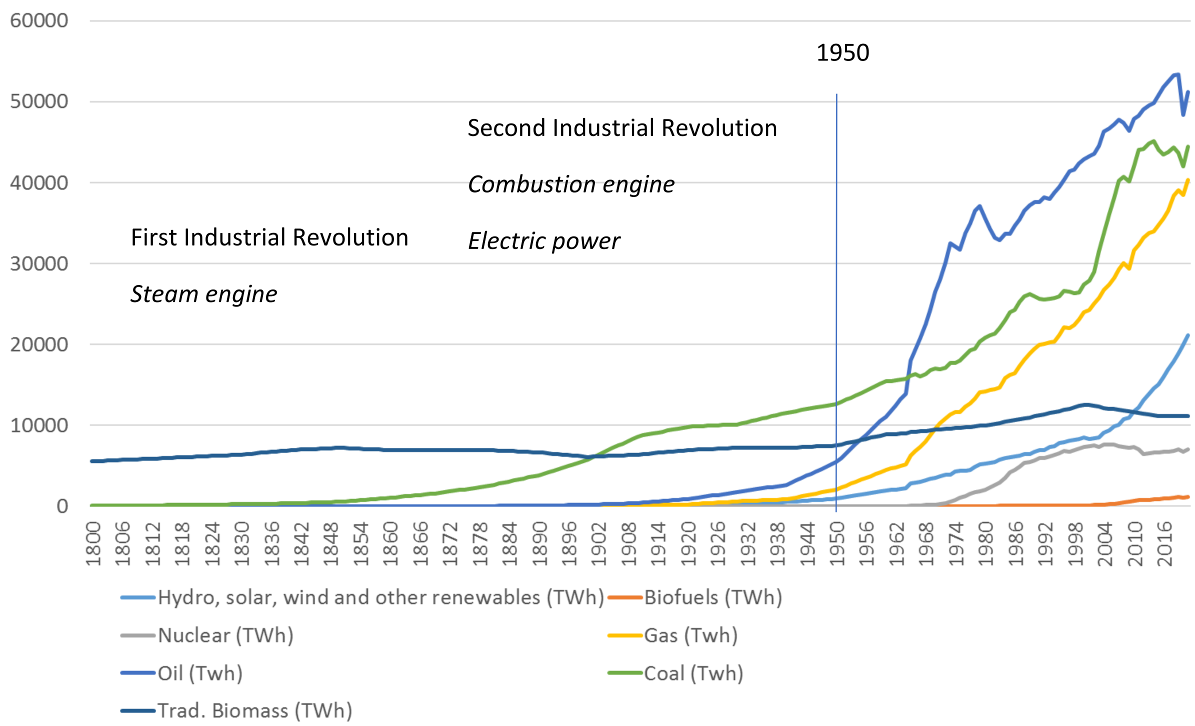
As nations grappled with the nuclear question, it became evident that energy transitions weren't linear processes, but were fraught with complexities and influenced by multifaceted factors. While there are no near-term limits on non-renewable uranium fuel supply, an expanded role for nuclear power will exacerbate concerns over high-level radioactive waste disposal, plant safety, and nuclear material losses and weapons proliferation (e.g. Salomon & Krishna, 2011). But with increased awareness of climate change, nuclear energy has received renewed attention. The scientific community is divided on whether a substantial expansion of nuclear power will be possible (Muellner et al 2021).

Finally, the history of the political economy of realizing advanced future technologies, as fusion power research has aimed to tackle global energy issues for roughly 70 years by now. Usually, projects have been organized as large state-funded enterprises with little or no private sector leadership. Partnerships between nation states have also been common, such as the European JET fusion research reactor in England and the global collaboration for the ITER facility in France (Nuttall 2023).

Climate change and the current energy transition

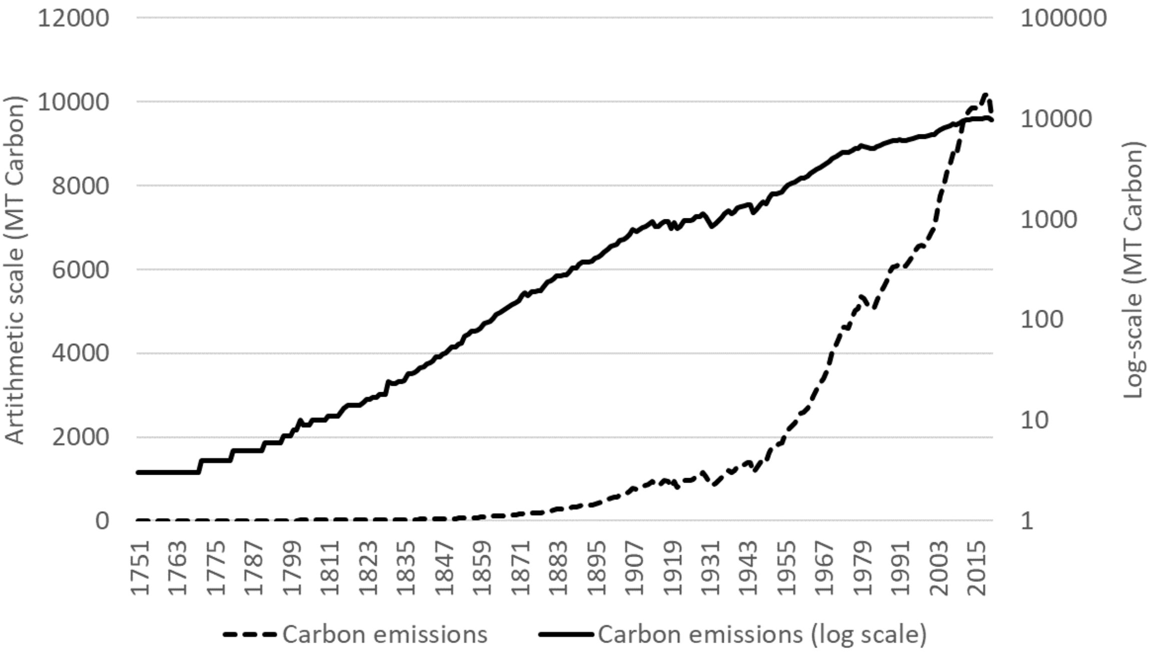
Even though the rise of agriculture, some 10.000 years ago have by some scholars been interpreted as an energy transition, for most of human history, energy use by humans was but a tiny fraction of the overall energy input to the biosphere. Several scholars regard the transition to coal has as the first major energy transition in human history, which marks the beginning of a fossil fuel energy regime. As mentioned, McNeill and Engelke (2016) have stressed the emergence of one big fossil energy regime, that have contained three sub-phases; the introduction of coal, then oil followed by natural gas. The total energy supply has continued to grow over these phases. This is of importance to environmental degradation and climate change. The notion of the so-called *Great Acceleration* (Steffen et al. 2007; McNeill & Engelke, 2014) corresponding to accelerated human impact on Earth systems after 1945, including anthropogenic climate change, is a question of scale. The shifting magnitude of energy supply around 1950 is evident from Diagram 1.

Diagram 1. World Primary Energy Supply by energy carrier (TWh) 1800-2020



Source: Our World Data

Diagram 2. Global Carbon Emissions 1751-2020. Million metric tons of carbon. Arthimetric and Logaritmic Scales



Source: Oak Ridge Laboratory.

As seen from the log scale plot in Figure 2, global emissions of carbon dioxide from fossil fuels had started to grow exponentially already in the late 1700s, with a roughly constant growth rate until the eve of the First World War. While the interwar period saw a slower growth of emissions, growth rates returned to 19th century figures in the Post War period. Since the early 1970s emission growth rates again slowed down. Thus, the beginning of the co-evolutionary process between fossil fuels and economic transformation, including economic growth, institutional and technical change, was at least 150-years old when planetary environmental degradation became evident as suggested by the Great Acceleration. This scale effect is illustrated by the arithmetic plot in Figure 2.

Because of climate change, the narrative of energy transitions is undergoing a fundamental shift. While historically, new energy sources predominantly supplemented existing ones, the modern discourse emphasizes a deeper transformation — an outright replacement of older energy sources (Fouquet & Pearson 2012). As Sovacool (2016) points out, our current global challenges, especially the urgency posed by climate change, necessitate a more radical rethinking. The idea is not just to add renewable sources to the mix but to replace carbon-intensive sources altogether. Moreover, York and Bell (2019) underscore this transformative necessity, highlighting that merely growing renewable energy is not sufficient. For a genuine transition, the challenge lies in systematically phasing out fossil fuels. This notion disrupts the historical pattern where the addition of new energy forms never resulted in the complete replacement of existing ones.

Furthermore, the impetus behind modern energy transitions is distinctive. Past transitions were primarily driven by technological advancements or economic motivations. In contrast, today's transitions are propelled by the urgent need to mitigate environmental and societal costs, as elucidated by Fouquet in his 2016 publication. Historical energy transitions have been driven by falling prices, which have been aided by political decisions. As Fouquet (2016) pointed out that it is not necessarily the price per unit of energy input (such as Joule or Kilo Watt hours) which is crucial from a demand perspective, but rather the price of the services, such as lightning and transportation, that are provided by energy. This implies that energy end-use has been important in driving energy transitions. As has been observed by Fouquet, if the price of the service fell sufficiently, either because the energy efficiency improved or the price of energy declined, full transitions could occur, as falling prices goes with rising demand (Fouquet, 2016, 8). Therefore, as the price energy services has fallen, the demand for energy has risen. In this context governments have invested in railways, roads, airports, harbors and electricity grids to mention a few infrastructures of crucial importance of energy transitions. The importance of energy end-use and energy services also highlights the problem of sunk cost. As energy demand is derived from the demand for services provided by capital goods, policies aimed at phasing out an energy source may render the capital good which provide the energy service, worthless

This current phase of a climate crisis in energy history is unprecedented. The stakes are higher, the challenges more profound, but so are the opportunities. The next era of energy will not just be about supplementing the old with the new, but about envisioning an entirely transformed energy landscape.

Concluding Remarks on Energy Transitions and Political Economy

Throughout history, energy transitions have been deeply embedded in the landscape of the political economy. While past research has majorly emphasized the nation-state as the central point of interest, it's evident that the concept of energy spaces extends beyond national territories. This is most apparent when observing the coal transitions in England, a subject of intense debate among economic historians.

The global narrative reveals that while individual nations might undergo unique energy transition experiences, a consistent theme is the prolonged nature of these transitions. As Smil postulates, these transitions often span five to six decades. Interestingly, these are not complete replacements but rather energy additions; the market share of new energy sources grows, with a 25 percent increase being a significant marker.

Formidable challenges posed by existing energy regimes. Established over centuries and having played a foundational role in the development of modern capitalism since the Industrial Revolution, these 'incumbent' regimes or ‘historical blocks’ are not easily displaced. The economic heft they wield extends into the political sphere, with numerous states deeply reliant on the revenues these regimes generate. At the same time, it is also worth noting the nuanced understanding of 'energy transition' in contemporary social science versus its historical interpretation. While the former often denotes the replacement of old energy sources with new ones, the latter typically alludes to a relative shift in energy sources. Historically, the latter appears to be more prevalent, possibly because relative shifts have been the norm.

One of the most pressing motivators of current energy transitions is the overarching aim to mitigate the societal costs associated with energy consumption. To accomplish this, new political tools and institutions are being established to facilitate technical and structural changes in the energy sector. This approach contrasts with the past when energy-related institutional changes usually aided ongoing energy transitions by fostering further falling energy prices. Contemporary climate policy aims at rising carbon energy costs, which, as reflected in powerful opposition to such policies, is politically costly. The pathway forward requires a profound understanding of these intricate relationships and historical precedents. Only by grasping the multifaceted challenges and opportunities of the past can we hope to navigate the complexities of contemporary energy transitions.

So far, mainstream economic and business history research have not yet engaged much with the current energy transition debate. At the same time, economic and business historians have paid interest to the interplay between energy supply, energy consumption, pollutive emissions and economic growth for several decades. The role of coal and relative factor prices are central for any economic historian studying the Industrial Revolution and modern economic growth, while business historians, at the same time, have been studying the growth of companies engaged in energy extraction and energy supply, including oil companies. But as this paper shows, economic and business historians have a great opportunity to get involved on a broad front in the ongoing scholarly energy transition debate. It urges economic historians to move beyond its traditional focus on how energy via technological change has created new economic growth opportunities and look more into the barriers for energy transition embedded in the architecture of the political economy.

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