WORKING PAPER

Schumpeter in the 21st Century: Creative Destruction and the Global Green Shift*

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***Chapter for inclusion in forthcoming book**

**"Schumpeter's *Capitalism, Socialism and Democracy* @ 75:
A Twenty first Century Agenda"**

Edited by Leonardo Burlamaqui and Rainer Kattel

Abstract

Schumpeter's evolutionary account of the technoeconomic dynamics of capitalism has been put to the test by himself in his analysis of the 19th century wave of development associated with iron and railroads, and by later scholars in the subsequent waves involving steel and electricity, then oil and automobiles, and finally information technology. Now there is a sixth wave emerging based on greening technologies and activities; it is coincident with the choices made by China in favour of renewable energy and resource recirculation through its relentless drive for industrialization. The Schumpeterian account provides the best explanation for this current global green shift and its Chinese driver.

Introduction

Amongst the many virtues of Schumpeter's *Capitalism, Socialism and Democracy* (*CS&D*) is its Chapter Seven on 'The Process of Creative Destruction'. In this short six-page exposition Schumpeter lays out his famous analysis of capitalism as a restless social and economic order that never is, and never can be, a stationary system. He paints a picture of capitalism as driven by 'gales of creative destruction' whereby innovation allows new players to enter markets and create new directions, financed by capitalist credit creation that puts the innovators on an equal footing with incumbents. The Schumpeterian analysis focuses on the evolutionary dynamics of the industrial system as it shifts from one technological trajectory to another. In the 75 years since his book appeared there have been numerous studies of industrial evolution and creative destruction, in such sectors as automobiles, electronics and IT. While valuable, these studies shed little light on the dominant trend of our time, which is the rise of China, followed by India, as emerging industrial giants. In this chapter the insights generated by Schumpeter in *CS&D* are applied to the dominant trend in our time, namely the rise of new green industries in China, with a focus on their evolutionary dynamics and potential to disrupt established fossil fuel industries in the West.

Indeed Western industrialism has achieved miracles, promoting unprecedented levels of prosperity and raising hundreds of millions out of poverty. Industrial capitalism is now diffusing east, where Japan was the first, then the four Tigers (Korea, Taiwan, Singapore and Hong Kong) and now China are all incorporating themselves into the global industrial world. India, Brazil and many others are expecting to follow the same course, which is best described as a Great Convergence. But as China, India, and other industrializing giants grow, they are confronted with an inconvenient truth: They cannot rely on the Western industrial development model with its fossil-fueled energy systems; resource throughput rather than circularity, and generic finance -- for reasons to do with extreme spoliation of their own environment and energy security and resource security concerns as much as concerns over global warming.

By necessity, a new approach to development is already emerging in the East, with China leading the way in building green industry at scale. As opposed to western zero-growth advocates and free-market environmentalists, it can be argued that a more sustainable capitalism is being developed in China – as counterpart to its all-too obvious black developmental model based on coal. In Hu Angang's words, this alternative is the 'inevitable choice for China' – and by extension, one might say for other developing countries as well. The tension between the green development pathway and the black pathway is a defining feature of the next Great Transformation.

The core elements of this emergent industrial model are 1) the enhancement of energy security through basing energy systems on manufactured energy devices – rather than extracting and drilling for fossil fuels in increasingly tense geopolitical locations; 2) the enhancement of resource security through restructuring the economy along circular lines (closing industrial loops) rather than the traditional linear economy; and 3) greening of finance to drive the transition. This new 'green growth' model of development, being perfected first in China and now being emulated in India, Brazil, South Africa (the BICS countries) and eventually by industrializing countries elsewhere, as well as by advanced industrial countries such as Germany, looks set to become the new norm in the 21st century. As Hao Tan and I put it in our article in *Nature*, 'Build energy security through manufacturing renewables'.

A Schumpeterian evolutionary dynamics approach to analyzing these trends, as opposed to neoclassical comparative static approaches that are obsessed with costs and with cost-based instruments like carbon taxes, promises to generate particular insights. Earlier sociotechnical transitions, as identified by Perez, Freeman, Berry, Louça and others, have been characterized by an emergent pervasive technology that has falling costs and costs lower than incumbent technologies and applications across the economy. The case can be made that the characteristics of the current transition to renewables energy systems and circular economy, is a sixth such wave. Like its predecessors, it is already starting to wreak creative destruction in established industries – as is felt in the coal industry, gas and oil, electric power generation and automobile industries as companies such as Tesla rewrite the rules of global competition.

While mainstream economists talk about the climate change challenge framed in terms of costs and the role that carbon taxes could play in driving alternatives, the reality seems rather to be that the energy and resources transformation that is under way calls for major structural changes and state intervention, best described in Schumpeterian terms. China's renewable energy revolution and circular economy initiatives are driving cost reductions globally, and creating business opportunities for new firms; this process may be viewed as the world's first case of a country breaking free of carbon lock-in by building its own domestic renewable energy industries and circulation of resources. As China grows its market for renewables and resource circulation, so its firms become more receptive to licensing advanced technologies from companies in advanced countries. These developments could create some complementarity between advanced firms in the West and Chinese mass producers – with the proviso that Chinese firms themselves are fast approaching the innovation frontier.

The test of Schumpeterian insights lies in their ability to shed light on contemporary industrial evolutionary dynamics. The global green shift that is under way is a case where the process calls for Schumpeterian insights in order to explain it adequately, and as a test case for the continued relevance of Schumpeterian evolutionary analysis and in particular the role of creative destruction in moving one technoeconomic system to another – or removing the vestiges of one system to create space for the new. The existence of these successive waves is an empirical reality; the real issue is the framing of a theoretically sound explanation for their rise and fall. In the current case of the global green shift the role of China in driving the process gives it added interest and relevance.

Long waves in the global economy

The study of long waves in economic life has many antecedents, amongst which the most celebrated are those of the Russian scholar Nicolai Kondratieff, who did his principal researches during the 1920s. Indeed his major work as known in the West was his long paper published in the German *Archiv fur Sozialwissenschaft und Sozialpolitik* in 1926.[1] Because he made the 'politically incorrect' finding that capitalism could go through evolutionary waves (in place of the terminal crisis favoured by the Communist International) he was shot by Stalin's secret police. Today we are allowed to study the long wave phenomenon with rather more political freedom.

Kondratieff's work was taken up by the doyen of business cycle studies in the US, Wesley Mitchell, in 1929, and by Simon Kuznets in his book on economic cycles, published in 193x. With these antecedents, it was Schumpeter who really championed Kondratieff, naming the wave that now bears his name in his 1939 masterwork, *Business Cycles*. So it was Schumpeter who was really responsible for introducing K to the west – and thereby breathing life into the evolutionary economics tradition. And Schumpeter made an important addition to K's long wave dynamics. K. had delivered himself of the observation that each successive downturn saw a cluster of technological innovations being introduced (because the conditions favoured innovation). Schumpeter took this observation and turned it into a driving force behind why one wave succeeds another.

This observation (or hypothesis) has been elaborated on by modern scholars including Ayres, Berry, Devezas, Freeman, Lloyd-Jones, Lewis, Louça, Marchetti, Nakicenovic, Perez, Tylecote and others, as well as Russians Grinin, Korotayev and Tsirel, while Modelski has traced the long wave concept back through 20 such waves occurring over the past 1000 years

[1] See Kondratieff (1926). This article was translated into English by W.F. Stolper and appeared in the *Review of Economic Statistics* in 1935. By that time Kondratieff was in prison in the Soviet Union, a victim of Stalin's purges. He was executed by firing squad probably in 1938. For a brief biographical treatment, see Grinin, Devezas and Korotayev (2012).

of globalization.[2] The central idea is that the economy is a dynamic, evolving system which moves through 50-60 year ‘spurts’, each driven by a new technoeconomic paradigm. It really is a scandal that so little work has been devoted to this central topic in economic analysis. The work itself seems to go through ‘cycles’ where there was an initial spurt triggered by Kondratieff himself and Schumpeter; then another cycle in the 1980s triggered by interest in an emerging fifth K-wave on the part of Perez and Freeman at SPRU and Ayres, Marchetti, Nakicenovic et al at IIASA, plus others like Berry in the US and Tylecote, Lloyd-Jones and Lewis in the UK. Now perhaps there will be a new spurt triggered by interest in a sixth wave emerging, based on greening trends, in the 2010s.

Schumpeter’s greatest contribution perhaps was his inspired guess that the long cycles revealed in capitalism by Nicolai Kondratiev were triggered by clusters of technological innovations. This has resulted in informed scholars identifying the ‘Kondratiev-Schumpeter’ long cycle evolutionary account of capitalism [e.g. Korotayev et al] – or what the Danish scholar Andersen tellingly calls the ‘engine of capitalism’ after Schumpeter’s own terminological innovation. Thompson (2012) looks to capture the same effect in the notion of technological clustering, which he suggests should be taken as the prime concept driving the evolutionary dynamics.[3] It is indeed a dynamic and disruptive account of evolution – not the incrementally progressive change assumed in mainstream neoclassical economics. As such it has great affinity with the punctuated equilibrium perspective in biological evolution, introduced by Gould and Eldredge, as an elaboration of the Darwinian approach which now dominates the field. Let me call this the ‘Kondratiev-Schumpeterian punctuated equilibrium’ approach to evolutionary economics.

K. holds pride of place as the real originator of the evolutionary perspective, or dynamic perspective, to which Schumpeter has made such contributions. It is fitting to honour them both in this chapter.

Five waves of industrial change

[2] As a sampling of the work reported, see Allianz (2006); Andersen (2002; 2009); Ayres (1990s; 1990b); Freeman (1983; 1997); Perez (1983; 1985; 2002; 2010); Freeman and Perez (1988); Freeman and Louça (2001); Korotayev and Tsirel (2010); Nefiodow (2006); Tylecote (1992); Lloyd-Jones and Lewis (1998); Berry et al (1993); and Nakicenovic (1989).

[3] See Thompson (2014):

The industrial revolution ushered in a totally new period of economic evolution, one that is known as ‘modern economic growth’ (Mokyr 2001; -- 2016).[4] The pre-industrial agrarian economy, with its rises and falls in wealth and income governed by crops and the weather, plus pestilence and war, gave way to a quite different kind of economy where systematic knowledge acquired by the scientific method became the basis of technologies and technological advance.[5]

Focusing on the technoeconomic drivers of change in our industrial system, we can draw from a Schumpeterian literature to identify five transitions in the period since the first transition, known as the Industrial Revolution – with a sixth putatively under way in the current period. The point is that each transition involves major social, technical and business upheavals that go well beyond mere economic substitutions effected by relative price movements. In my own work on this topic I have identified two streams of literature as making a major contribution. There is the stream that focuses on the actual K-waves as measured using sophisticated statistical techniques – as done by K himself and subsequently by Berry and most recently by the Russians Korotayev and Tsirel -- in work validated by Devezas (2014).[6] And there is a stream that focuses on the institutional details of each shift in technoeconomic paradigm, with a clear focus on the ‘reverse salients’ involved and the struggles between the emerging technologies and business interests and the vested interests defending the status quo.

The key point is that the waves involving upturns and downturns in economic categories – from prices to GDP to industrial sectors – are an empirical reality, obvious to all who are prepared to look at the evidence. But what accounts for these waves is anything but obvious – in fact to find an adequate explanation must count as one of the greatest problems of the social sciences. Schumpeter himself started an extremely fruitful line of advance with his hypothesis that the successive waves are driven by spurts of new technoeconomic clusters. But then there is the issue as to what drives the clustering of technological innovations.

Let us look at the data first, prior to framing hypotheses. The most widely accepted dates for the five waves of technoeconomic change since the industrial revolution are those

[4] See Mokyr 2001; -- 2016.

[5] It is fitting to describe the agrarian economy as Malthusian, since it was best described by Thomas Malthus at the very moment that it was disappearing in the early 19th century.

[6] Devezas (2014) reports on a spectral analysis of the unfolding of global GDP growth rates, where cycles of periods 7.5 years, 15 years, 32 years (weak) and 52 years (strong) are clearly identified.

provided by K&Ts, as given in Table 1. Each wave with a clear upswing and downswing, can be dated more or less as follows.

Table 1. Upswings and downswings in industrial capitalism, 1760-2011

Long wave number	Phase	Onset	Ending
1st	A: upswing B: downswing	1780s 1810-17	1810-17 1844-51
2nd	A: upswing B: downswing	1844-51 1870-75	1870-75 1890-96
3rd	A: upswing B: downswing	1890-96 1914-20	1914-20 1939-50
4th	A: upswing B: downswing	1939-50 1968-74	1968-74 1984-91
5th	A: upswing B: downswing	1984-91 2008-2012?	2008-2012? ?

Source: based on Korotayev and Tsirel (2010), Tables 1, 2, p. 2

In brief, the initial surge was driven by new developments in water technology, both in terms of power (water wheels) and transport (canals), involving the factory mode of production itself and new sources of power such as steam. The first steam engine (or 'atmospheric engine') was demonstrated by Newcomen in 1712; it was put to use in pumping water out of coal mines. The Boulton and Watt partnership was created in Birmingham in 1775 as a means of exploiting Watt's patent on the steam engine with separate condenser; the firm became a driving force as its expanded in the 19th century. The shift to the downswing occurred during the Napoleonic wars. The principal industry utilizing the new water power and steam power was textiles, particularly cotton – the first 'carrier industry'.

A new wave was initiated by the development of steam power applied with greater efficiency to factory work and to transport, in the form of a moving locomotive. The new surge was carried by vast investments in railroads, as tracks were laid across Europe and the US after being pioneered in Britain. The key factors in the second wave were thus steam and iron, which were able to overcome the incumbent water-based systems as their costs declined, provoking the 'canal panic' of 1837. The Great Western Railway founded in 1833, received its enabling Act of Parliament in 1835 and operated its first trains in 1838 – marking a significant moment in the second Kondratieff. In the US the Union Pacific Railroad was founded with Act of Congress 1862, during the Civil War.

Moving closer to the modern era, a third wave of investment and technological change plus creative destruction was launched by both steel and electric power in the 1890s, in a new upswing terminating the long depression that lasted from the 1870s to the 1890s. The new electric motors were pitched against the incumbency of steam power, and triumphed in the early years of the 20th century because of falling costs and because of the greater efficiency of being able to harness power to machines wherever they were used, rather than from the central 'prime mover' that characterized the steam-powered workshop. It was the Bessemer process that transformed the world of iron into a world of steel – and it was the founding of a new steel company in the US by Andrew Carnegie in 1872, based on the Bessemer process that launched a new era and resulted in the formation of US Steel. In the new world of electric power the greatest innovations were by Westinghouse and Edison and Tesla, resulting in the formation of major K3 firms General Electric and Westinghouse. In Germany which was also rising to industrial leadership the major firms founded at the time were Siemens and IAG, which became the core of Germany's subsequent technological supremacy.

The heavy engineering of the 3rd K-wave proved to be a major impediment to its diffusion, and it proved no match for a fourth K-wave which was launched in the early 20th century with the arrival of the internal combustion engine (ICE) and the external combustion engine (diesel engine) as motive power for individual transport vehicles. This was the K-wave of oil, with the automobile as lead industry and mass production as lead organizational form. The origins of the K4 wave lay in the introduction of mass production principles by Henry Ford in the automobile sector, perfected at the Highland Park (Michigan) plant in 1915, introduced during the downswing of the K3 wave. The introduction of this mass produced car to the market was followed by unprecedented market expansion and cost reductions that flowered and diffused worldwide in the postwar boom (upswing of the K4 wave) – and that provide a glimpse of what is happening with green products such as renewable energy devices today.

The K4 wave is generally reckoned to have come to an end during the 1970s and 1980s as financial crashes triggered new speculative booms – this time focused not on hardware like cars and white goods but on computers and information technology and the software that drove these new ‘intelligent’ devices. Early innovations were the transistor created as first solid state device in the 1960s and then the first ‘chip’ created by Intel in 1970 followed by the microprocessor in 1971. New fortunes in IT and software were created by completely new firms like Microsoft, Apple, Symantec and Oracle. The early investments were made in the downswing of the K4 period, only to bloom and flourish in the upswing of the K5 wave, in the late 1980s to the early 2000s.

This timing of successive waves dates our present period as the emerging downswing of the 5th K-wave, when investments in IT and knowledge industries continue to be made at scale but cannot be expected to carry the global economy to new levels of prosperity. Instead investments in a new key factor are needed to do the job – and the best candidate for this new role is greening. [Others such as Nefiodow and Nefiodow (2014) and Allianz have opted for biotech and personalized medicine, which I agree is a world-changing technological innovation but in my view is likely to see its flourishing in the next K-wave, after the conditions favourable to it are created by the emerging 6th wave.]

Technoeconomic paradigms and their shifts

There are several sources that feed into this present exposition of a sixth wave transforming the global economy and shaping cities in a new urban geography. The first is Schumpeter himself and his fundamental conception of the evolutionary character of the capitalist system, or what he liked to call the evolution of the capitalist engine (a phrase picked up and utilized to great effect by his expositor, Esben Sloth Andersen in his 2009 masterwork). Central concept in this stream of work is the notion of creative destruction, and the long waves initiated by innovation (or clusters of innovative products and technologies). It is perhaps not widely appreciated that it was Schumpeter who really ‘imported’ Kondratiev and his long waves theory into Western economics – and gave the K-waves a theoretical underpinning in the form of technological innovation that they had not had in Kondratiev’s own work. So this is an enormously fruitful starting point – and puts Schumpeter on the same level as Darwin as evolutionary theorist.

Then there is the stream of work that elaborates on long waves and structural crises of adjustment, in which the work of Freeman and Perez (1988) is fundamental, with its central notion of sociotechnical paradigm and the series of shifts in such paradigms culminating in the emergence of a fifth such shift in the 1970s. This fundamental text introduced its taxonomy of innovations, as encompassing (1) incremental innovations (the most common); (2) radical innovations; (3) changes of technology system – where both radical and incremental technical innovations combine with organizational innovations; and (4) changes in 'techno-economic paradigm' – the most fundamental and far-reaching of all. It is viewed as having pervasive effects throughout the economy.

As elaborated by Perez in successive papers (Perez 1983; 1985) and by Freeman and Perez (1988) each successive TEP is characterized by a key factor or dominant cluster of technologies that have the characteristics:

1) Clearly perceived low, and rapidly falling costs;
2) Apparent almost unlimited supply over long periods; and
3) Clear potential for the use or incorporation of the key factor in many products and processes throughout the economic system.

The crux of their paper was the demonstration that these characteristics at the time held most persuasively for IT and IT-related products, i.e. products of miniaturization, electronics, and digitalization. Moving backward in time they argued that these characteristics held for the key factor of the 4W (oil) and (by extension) for mass production and the automobile. Further back the key factor of the 3W they argued to be low-cost steel (rather than electric power); and in the 2W low-cost steam-powered transport in the 2W. Perez herself in her 1983 and 1985 papers had referred to 'technological styles' as something that encompassed more than 'just' an innovation. By the 1988 paper she was happy to adopt the terminology technoeconomic paradigm (TEP)

In a manner closely similar to Freeman and Perez (1988), I wish to argue that an emergent wave is based on the *key factor* input of renewable energies and circular economic system (CERES) packaged together in eco-cities (or smart cities), where we see (1) drastically declining costs (and where the argument is that their costs are declining for fundamental reasons related to the fact that they are products of manufacturing); (2)

unlimited supply of renewable energy sources (and recirculation of material inputs, potentially endlessly); and (3) demonstrated potential for incorporation in power systems, food production, water regeneration and in manufacturing and transport generally. In addition to key factors satisfying conditions of having low and descending relative costs, plus virtually unlimited supply and potential all-pervasiveness, Perez (1983: 4) specifies that a new key factor should also demonstrate the potential to reduce costs of capital and other inputs into productive activities.

If we include this fourth element as well, we see that it too fits the introduction of renewable energies and recursive materials systems since these elements have the demonstrated capacity to reduce costs for all other factor inputs (e.g. as water costs increase, due to scarcity, so water regenerated in renewable energy powered desalination systems becomes relatively much more cost effective).

As an aside, note that the frequently advanced argument that in the eyes of consumers there is nothing to distinguish 'green' electricity derived from renewable sources from 'brown' electricity derived from fossil fuels, has no bearing at all on the Schumpeterian arguments being advanced here. The TEP based on fossil fuels is being superseded by RE-based power systems not because of perceived differences between 'green' and brown electric power (appealing to moral and ethical choices) but because the RE-based power is falling in cost relative to fossil fuel-based power, and the RE-based power is finding wider and wider applications, e.g. in urban food production and urban water regeneration.

Perez (1983) further clarifies the mode of diffusion of the new TEP through applications across multiple sectors. If the key factor for the sixth wave (6W) is renewable electrical power, generated from renewable devices like wind turbines and solar cells, then we need to look for multiple applications of renewables across multiple sectors. These would include food production and water regeneration, where urban-based innovations are emerging based on the capacity to supply virtually unlimited energy from solar and wind sources. It would be most accurate to call the 6W key factor the complex of renewable energy generation and energy storage technologies that can feed a steady (if fluctuating) supply of power into an IT-enabled grid called the smart grid. This complex of IT-enabled renewable energy technologies constitute a 'key factor' that can be seen as enjoying steadily reducing costs (and prices) based on the fact that all the activities involved depend on the production of manufactured devices. Because of these low costs and falling costs associated with manufacturing experience curves, the 6W key factor is having widespread effects, bringing renewable electric power to ever-widening circles of users and upgrading the reliability and resilience of electric power grids.

The 6W motive branches are those that are involved in the manufacture of renewable energy devices (e.g. wind turbines and solar PV cells), energy storage devices (e.g. lithium-ion batteries) and electric grid devices (e.g. inverters, energy centres). The prosperity of these motive branches rises as the adoption of the 6W energy systems diffuses. Correspondingly the 6W carrier branches are the power generation systems as well as electric vehicle systems that utilize the key factor of renewable electric power. These too are products of manufacturing and reduce in cost and price as a result of the experience curve.

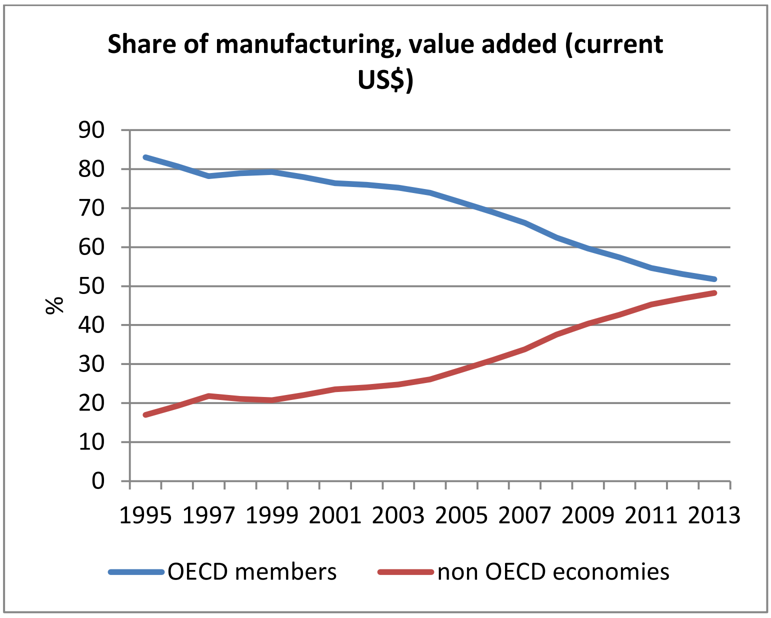
Thus we can identify 'induced branches' as those that are related to the diffusion of the carrier branches, such as the manufacture of EV charging stations, battery replacement stations for EVs and other such sectors that have no role in the fossil fuel economy but constitute essential infrastructure in the 6W economy. We see then that *manufacturing* is the activity that is common to the key factor itself (renewable electric energy) and to the motive branches, the carrier branches and most of the induced branches.

Perez (1983) elaborates on the downswing of a given Kondratiev as being characterized by exhaustion of the technical and economic opportunities available in the current TEP, thereby opening up space for the new technology cluster to impress itself. Thus we may point to the exhaustion of the fossil fuel based energy industries and carbon-fueled industries, while dramatic new opportunities are being opened up by RE powered systems and new industries – from power production, energy storage, to EV transport. The exhaustion is clear when we look at the wave of bankruptcies in coal producers (e.g. Peabody); in electric power generators (e.g. abrupt shifts in business model by RWE et al in Germany); and impending bankruptcies in automobiles as EVs start to take over.

The green shift of 21st century as 6th K-wave

Now there is a powerful argument linking the global green shift as dominant technoeconomic development to the geopolitical shift that sees the rise of China as an industrial giant. Let us then review the evidence supporting the claimed shifts that are the dominant trends today – the shift in manufacturing east, and the green shift away from fossil fuels. They are in fact linked, at a profound level, because it is China that is driving the shift of manufacturing east, and as it does so, it is having to drive the green shift as well.

Fig 1 Manufacturing moving east

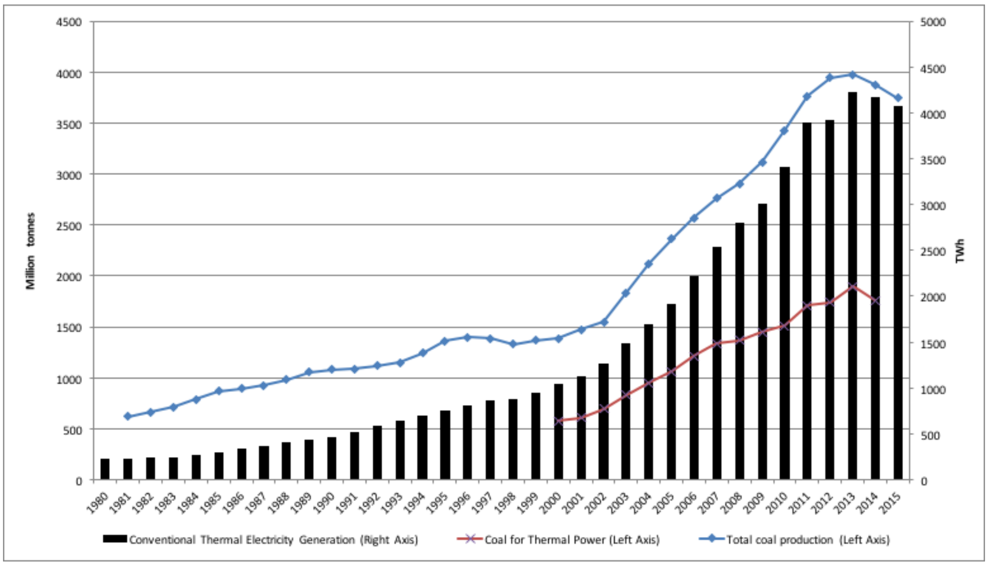


Source: OECD Development Centre

Our starting point is the green shift that is currently under way in the industrial economies – including (and especially so) in the rising industrial giants, China and (to some extent) India. As China and eventually India build their vast manufacturing engines, so they discover the need to power them with energy sources – of which fossil fuels are the obvious and initially favoured candidates – just as has been the choice made by all previous rising industrial powers.

The green transition that is currently under way is the single most important feature of the current world, along with the rise of China as the world's premier manufacturing power. Indeed the two features or processes are tightly linked, because China's rise is based on the building of a huge energy system to power the manufacturing system, and China has discovered the limits to trying to build this energy system on the basis of fossil fuels. The limits are not so much commodity supply limits of the course investigated and popularized by the Club of Rome study of 1972 on *Limits to Growth*, but rather geopolitical limits as China finds that its quest for resources and especially fossil fuels around the world runs into problems involving civil wars, revolutions and terrorism. Compelled by these factors, along with the terrible immediate environmental problems created by China's headlong rush to industrial maturity, China is finding that conventional energy and resource strategies ("business as usual") no longer work, and it is instead engaging in an alternative "green growth" strategy that is proving to be very successful. This alternative is driven by reducing costs, market expansion and manufacturing innovation as China becomes principal global player in installing renewable energy systems (such as wind power and solar photovoltaic cells) and in manufacturing the devices needed to capture the renewable energy sources. China's green and black strategy is easily seen when we look at longitudinal data on electric power generation.

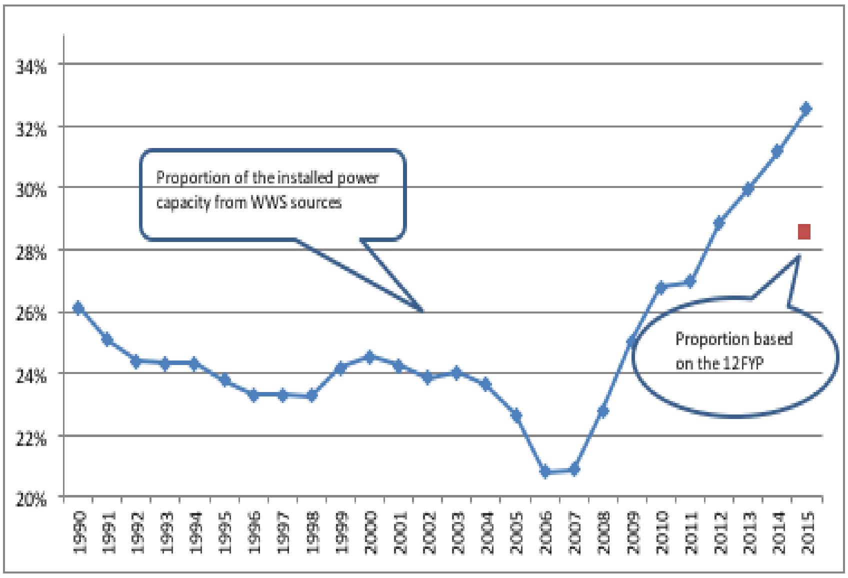
Figure 2. China's "green and black" energy system, 1980-2015



Source: Mathews (2016).

The effect of this rapid expansion of fossil fuels input in China is well known – it is unbreathable air and undrinkable water, combined with rising geopolitical tensions as China (and now India) scour the planet for fuels and resources. But China has stumbled on an effective remedy for these problems – renewable energies and urban mining or recirculation and regeneration of resources. The evidence demonstrating this shift is again clear and unequivocal. Consider Figure 3, which shows the rapid increase in proportion of electric power generated from water, wind and sun – rising from a low of 21 percent a decade ago to reach 33 percent in 2015 – more than 10 percent change in a decade. This is an astonishing rate of change for such a huge system with its vast fossil fuel infrastructure.

Figure 3. Greening of China's electric power system, 1990-2015



Source: Mathews and Tan (2015)

The conventional economic account of this green shift is to focus on switching from one energy system to another as a matter of substitution, where price of one commodity/product versus another is determined in some equilibrium framework. Policy initiatives can be taken in such a framework by cost-moderating instruments like green taxes or market mediated caps on emissions. Apart from the fact that such interventions have proven to be very weak when put into practice, and stand little chance against the raft of subsidies that have historically supported the fossil fuels system (oil and gas industry, coal industry, power generation industry), these equilibrium-based instruments offer precious little insight into the workings of energy industrial dynamics. But Schumpeter's approach, as exemplified in his major books (the youthful *TED* and more mature *BCs*) and briefly in his *CS&D*, is far richer, and will generate far more fruitful insights than the conventional approach.

If we start with the concept of creative destruction, we see that Schumpeter's approach in *CS&D* would imply that the rise of a new cluster of renewable energy industries would be accompanied by the decline and fall of traditional industries, namely those based on fossil fuels. This is an evolutionary perspective, one that views the energy sectors as being in perpetual disequilibrium and shaken by waves of firms deploying new energy technologies taking over from those that cling to the prevailing technologies. The mode of supersession of one industrial cluster by another was always the focus of Schumpeter's analysis – as it needs to be in the case of the 21st century shift in energy and resource systems.

Schumpeter himself took the trouble to exemplify his evolutionary analytical perspective by utilizing the case of "railroadization" in the 19th century. This is what the current Danish Schumpeterian scholar Esben Sloth Andersen has called Schumpeter's principal case and reference point in describing the evolutionary dynamics of capitalism. Now we can take a similarly important case, around 100 years after Schumpeter's major scholarly interventions, in the form of the global greening shift that is having widespread creative destructive efforts worldwide.

I take Andersen as the most insightful guide to Schumpeter's approach to evolutionary capitalist dynamics.[7] Andersen doesn't get caught up in the endless debates over whether Schumpeter's framework was "evolutionary" or "developmental" but settles clearly in favour of evolutionary – in keeping with the modern interpretation of the term. Then taking railroadization as the key-idea dominating the second long wave after the European (British) industrial revolution, the process of supersession of the old (in this case, mail coaches on the one hand and canals on the other) by the new (railroads) can be seen to move through four phases (2002: 48):

1. We start with a system that is fully developed (mail coaches) and which is nurturing the new (railroads) in small niches;
2. Swarms of innovative (railroad) investment projects and clusters bring the new (railroads) to compete seriously with the existing system, on the basis of finance made available to entrepreneurs through bank credit and the capital markets;
3. Sooner or later the adaptive forces of economic life establish a new norm, based on railroads (through several cycles of relatively routinized investment), with the new driven by a cluster of related innovations (in traction, railroads, gauges, passenger management); and then

[7] Andersen's 2002 paper in *Industry and Innovation* is probably the best piece of individual scholarship that I published in *I&I* when I was editor, in the years 1994 to 2004.

4. The long wave matures and nurtures within itself a new, emergent cluster of technologies (e.g. electrification) and organizational innovations (e.g. trusts).

The virtue of Andersen's revision of Schumpeter's evolutionary account is that he brings out the theoretical core in the form of the identified logistic industrial dynamics, as well as the institutional details of the creative destruction involved.

Essentially, greening is a process of creative destruction – a destruction of the entire fossil fuel industrial order and its supersession by an alternative energy and resources order based on renewable inputs. This is not the mere substitution of one or two products by different products – as in electric power produced from coal substituted by electric power produced by wind and sun. Rather it is a whole system transition or shift from one system based on fossil fuels to another system powered ultimately by renewables. A technoeconomic system transition implies taking cognizance not just of prices (as in the equilibrium-based mainstream economics perspective) but of technologies (e.g. wind and solar power devices and their use to generate power, or EVs and batteries); infrastructure (electric power smart grid; EV charging stations); government policies (e.g. feed-in tariffs; public auctions of renewable energy concessions); and institutions and business models.

Correspondingly a Schumpeterian perspective on creative destruction focuses attention on the means of resistance waged by the incumbent firms and the technologies they support, as they strive to delay or block the supersession that is under way.

All these features can be seen in the current green shift that is diffusing worldwide. And just as there was a lead country with its lead firms driving previous technoeconomic shifts, so there is a lead country in the 21st century driving the shift to a green economy. In the 19th century there was the shift from mail coaches and canals to railroads, when the lead country was initially Britain later followed by Germany and the USA. In the late 19th and early 20th century there was the new wave sparked by electrification, where the lead country was the USA and to some extent Germany. In the 20th century as the fourth Kondratieff unfolded, based on oil, automobiles and mass production, the lead country was definitely the USA and leading firms like Exxon-Mobil, GE, GM and Ford were American. In the late 20th century 5th Kondratieff based on IT/ICT, there has been a multipolar expansion with the lead shared at different times by US, EU and Japanese firms. Now in the 21st century we see the emergent 6th wave driven by applications of IT to energy and electric power, to food and water production and regeneration, and to the shaping of cities themselves as the envelopes of further technoeconomic advance – with China emerging as the lead player as it moves rapidly from imitation to innovation.

Schumpeterian analysis superior to that of neoclassical economics

My purpose in this chapter is to draw out the contrast between a neoclassical economics perspective and the Schumpeterian perspective on the global green shift. The neoclassical perspective, which for some strange reason still manages to maintain its dominance, is based on microeconomic static reasoning, i.e. micro reasoning at a point in time. Based on the prevailing equilibrium assumption, the insights offered are that as the price of some factor of production changes so its utilization in the production function will shift. In the case of energy inputs, the neoclassical framework contrasts fossil fuel energy inputs with renewable energy inputs in terms of current prices – and based on an externally induced crisis (namely climate change) it generates a policy proposal to decarbonize energy inputs, through the medium of raising the prices of fossil fuel inputs. The most straightforward way to do so is through a carbon tax – although there are other means of making fossil fuel inputs less attractive such as cap and trade schemes, whereby producers are allocated a 'cap' on their carbon emissions and are enabled to trade these allowances in a carbon market.

These schemes of one kind of 'environmental taxation' or another are discussed in a setting where an external threat is perceived and a moral duty to act to avoid the threat is posed. The problem is that the political resistance to such environmental taxes by vested interests is profound and determined, so much so that there has been precious little progress achieved globally in reducing carbon emissions over the 20-plus years of operation of the UN-sponsored Kyoto Protocol. And sometimes the moral imperative is posed with breathtaking arrogance as when a political party in the advanced countries ignores the moral imperative incumbent on themselves and calls down divine punishment on governments in developing countries where fossil fuel usage is rising, as a result of their implementing a strategy of industrialization. India and China are the two countries that are receiving most of this opprobrium.

This neoclassical economics framework is entirely contingent, and frames the shift that is observable as a price-mediated substitution of one input by another, without any sense of where the system might be headed, and why. The story told is simplicity itself. In the past there was an effective shift to fossil fuelled energy inputs, powering a wave of wealth-enhancing industrialization. Today the environmental costs of these are discovered and so economists advocate a carbon tax to induce price-guided substitution of energy inputs. The fact that they have been advocating the same policy for some 30 years with very little to show for their efforts is not – apparently – seen as a negative. It is put down to the fact that major substitutions are politically complex and difficult to achieve.

By contrast a Schumpeterian perspective puts the green shift in a plausible industrial and historical setting, and frames realistic proposals as to how it may be achieved or accelerated. First, the green shift is viewed not as a unique occurrence but as the latest in a series of technoeconomic shifts – each one driven by the same kind of concatenation of events. The economy is viewed not as a series of static adjustments but as an evolving system. The driver of change is the technoeconomic character of the economy at a point in time, where long-term waves of development are observed empirically, and theory is developed to seek to account for these wave-like shifts. An existing technoeconomic paradigm (TEP) is ousted by a successor, whose existence can be validated by reference to the parallel shifts that have occurred in the past.

From this perspective, the current green shift may be viewed as the sixth such transformation since the industrial revolution, where each period is characterized by a dominant technoeconomic paradigm that rises according to well-recognized dynamics and is in turn ousted by a successor. This historical perspective draws attention to the dynamics of the shift, looking to identify the motive forces (key factors) that are generated as well as their carrier industrial branches and their induced branches. The focus on the dynamics of the process calls attention to the roles of investment, with varying roles to be anticipated to be played by the financial sector as well as the real productive sector – according to the insights of Carlota Perez and others.

When we combine geopolitical insights with those from industrial dynamics we get even closer to the present realities. In the case of the global green shift we have the simultaneous occurrence of a shift in manufacturing east (specifically to China in the first instance) plus the shift in terms of industrial dynamics to a post fossil fuel world. And these two trends are in fact deeply connected. As China industrializes (which it is pursuing in the name of enhancing wealth and income) so it finds it necessary to build a vast energy system to power its growth in manufacturing. It starts, of course, with fossil fuels – like all previous industrial powers. As it does so it comes across not just immediate environmental limits to expanding the scale of fossil fuel usage (unbreathable air and soiled water) but geopolitical limits in the form of threats of war, revolution and terror as China penetrates less and less stable regions of the earth in search of fossil fuels (and resources) that are less and less accessible. And so China looks actively for an alternative to fossil fuels in order to enhance its energy security.

Thus we have an argument that starts with empirical realities, namely the observable green shift that is under way together with the shift eastwards in manufacturing and the energy choices that are imposed on China to drive this industrial engine with some degree of energy security. And we have a theoretical explanation for these shifts in terms of a clustering of green energy technologies that are becoming available (as the grip of fossil fuels is loosened) and are driven by China as the optimal candidates for powering China's industrialization – because as products of manufacturing they give energy security in place of the geopolitical insecurities associated with extraction of fossil fuels and resources from terrestrial locations randomly allocated.

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