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The sixth technoeconomic paradigm

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Abstract

There is wide agreement that there is underway a surge in investment in renewable energies and clean technology, and that this investment is facing considerable obstacles in the form of 'carbon lock-in'. Nevertheless the tools of Schumpeterian analysis updated with a Freeman/Perez techno-economic paradigm shift framework, have rarely been employed in analyzing the phenomenon. This paper utilizes such a framework to make the argument that the shift to a clean technology regime is actually a broader shift in techno-economic paradigm, ushering in the sixth such shift since the industrial revolution. The core of the paper is a characterization of the emergent sixth technoeconomic paradigm in terms of seven organizational principles, bringing out the differences with earlier industrial paradigms. The theoretical and practical implications of adopting such a standpoint are teased out, and the policy implications developed.

Keywords: renewable energies; sixth techno-economic paradigm shift; neo-Schumpeterian dynamics; carbon lock-in; climate change; creative destruction

Introduction

It is difficult now to recall the excitement that greeted the announcement by Perez and Freeman, writing in a neo-Schumpeterian tradition, that the surge in IT investments witnessed in the early 1980s were not just technology-specific developments, but actually embodied a shift in techno-economic paradigm. Perez (1983; 1985) and Freeman with Perez (1988) made the case that the countries that best adapted to and exploited the potential of IT were those that made the structural adjustments to an economy where IT provided the pervasive driving technology. They identified this shift as the fifth that had occurred since the industrial revolution, and characterized it as being a techno-economic paradigm (TEP) shift insofar as its dominant technology enjoyed falling costs; was under-pricing its incumbent technological competitors; and was pervasive in its effects. Perez and Freeman went further and characterized the organizational features of the emerging 5^{th} TEP shift, such as flexible departures from the rigid hierarchies associated with successful 4^{th} TEP ("mass production") firms, and argued that the firms, regions and countries that adopted these organizational principles would be the ones that did best in the new IT-era. It was no accident that others such as Piore and Sabel (1984), with their similar notion of "flexible specialization" were writing at the same time and employing a similar kind of analysis.

Fast forward three decades and we face a comparable situation. There is a new surge of investment in a new technological wave, associated with renewable energy and clean technology. There is a strong case to be made that this new technological wave enjoys (dramatically) falling costs; that it will shortly be priced at well below its fossil-fuelled incumbent competitors; and that it will be pervasive in its effects. Going further, it is feasible to argue that this emerging technology wave has very different organizational foundations from its fossil-fuelled predecessor, in that it favours decentralized renewable energy generation and open competition between a variety of energy generating systems, as well as an emerging international market for renewable electric power. Put these ingredients together, and you have an emergent, sixth techno-economic paradigm shift.

The mystery is why so few neo-Schumpeterian scholars are embracing such a viewpoint.

This paper builds on the work of Mathews (2013) to consolidate the case that there is indeed a sixth such shift underway. To drive home the argument, the features identified by Freeman and Perez and associated with the 5th TEP shift are recapitulated and then tested to see whether the current shift to renewables and clean technology satisfies the same conditions. The organizational features of the emergent 6th TEP shift are then explored. The argument is cemented by demonstrating that it is consistent with other accounts of the emergent cleantech era, such as a third energy industrial revolution (Rivkin 2012) and the demonstration by Korotayev and Tsirel (2010) that the global economy is currently on the cusp of a second sub-wave of investment as the world moves from the 5th to a successor TEP. Finally the implications for both theory and practice are developed. In particular, the emergence of a new 6th TEP shift opens up new possibilities for relevant research on the part of the neo-Schumpeterian community – research that will engage with big issues including climate change, the emergence of China as a new industrial power and the processes of technological transition.

Technology cycles and techno-economic paradigm shifts

The characterization of periods of upsurge (upswings) and downswings, across the entire global capitalist economy, is subject to a great deal of strenuous scholarly effort and disagreement – and in the absence of any definitive study of the economic history of the industrial era, some caution is needed in characterizing successive surges. Building on the work of Kondratiev (1935) and then of Schumpeter (1939), most scholars who have examined the matter (e.g. Freeman and Louçã 2001) are agreed that there have been five such upswings and downswings since the industrial revolution – as shown in Table 1.

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 (1815*) 1844-51 (1848*)
2nd	A: upswing B: downswing	1844-51 1870-75	1870-75 (1873*) 1890-96 (1895*)
3rd	A: upswing B: downswing	1890-96 1914-20	1914-20 (1918*) 1939-50 (1940*)

4th	A: upswing B: downswing	1939-50 1968-74	1968-74 (1973*) 1984-91
5th	A: upswing B: downswing	1984-91 2008-2010?	2008-2010? ?

Source: Mathews (2013), based on Korotayev and Tsirel (2010), Tables 1, 2, p. 2; starred dates in brackets are those given by Freeman and Louçã (2001).

The analysis of such periodic patterns of upswing and downswing is not pursued by neoclassical economists – meaning that the central features of the global capitalist industrial economy remain under-explored by the economic mainstream. One might hazard a guess that to do so would negate the core assumptions of equilibrium that underpin the entire neoclassical economic corpus. Nevertheless if one adopts the perspective that empirical analysis should come first, and theoretical analysis to explain the empirical findings should then be employed, these cyclical processes cannot be ignored; indeed they cry out for an explanation.

One of the most widely accepted theoretical frameworks for discussing technological change, and periodic 'technology surges' and the creative destruction they generate (doing away with the old and creating space for the new), is that of technoeconomic paradigm shifts, as expounded by Freeman and Perez, and which is in turn based on a close reading of Schumpeter's business cycles and Kondratiev long wave theory.[1] Perez (2002) provides the key to making the connection between technological and financial dynamics in her notion that while the dominant TEP is moving through its mature phases (late deployment and decline) the new paradigm is gestating and moving into early-phase installation. The argument to be developed in this paper, in a nutshell, is that this is precisely what is occurring with the case of the upsurge in investments in renewable energies and clean technology.

Perez (1985) identified a 'key factor' with each TEP, and characterized it in the following terms: it has declining relative costs; its supply is virtually unlimited; it has massive potential

[1] There are in fact two strands of this framework. There is Freeman (1986; 1983) and Perez (1983; 1985) and what emerged as a joint vision in Freeman and Perez (1988), where the emphasis is on the triggering of new long waves by clusters of innovations, and upswings and downswings reflecting the struggles of the new to be born and the old to refuse to die. Freeman and Perez identify five such shifts or technology surges – the latest being the surge associated since the 1970s with the introduction of IT and ICT technologies. Then there is a second strand initiated by Perez herself, where she links the technology narrative with financial investment, speculation and bubbles – as in Perez (2002; 2011). The approach associated with Perez is updated and expounded in Drechsler et al (2009).

for applications and so for becoming pervasive; and it forms a core element of a complex of technologies, processes and institutions. The principal proposition of this paper is that renewable energy and cleantech more generally constitute such a key factor in the emergence of a sixth TEP.

Intimations of the emergent 6th TEP

Scholars oriented towards systems analysis of energy systems (and particularly those associated with the journal *Technological Forecasting & Social Change*) have long been debating the role of energy systems as foundational elements of successive technoeconomic transitions. Marchetti (1977) pioneered such an approach, and it has since been expanded to encompass the global economy into the 21st century (e.g. Devezas 2010). The problem is that many of the predictions were based on falling carbon content in traditional fuel-based systems, moving from coal to oil to gas and ultimately hydrogen, and viewing energy alternatives solely in terms of nuclear options – whereas what is apparent in the 2010s is that the world is on the brink of a fundamental transition away from fossil fuels and nuclear and moving steadily to a new energy paradigm based on renewables (solar, wind, geothermal etc.).

The polymath author Jeremy Rifkin adopts a stance that is complementary to a sixth TEP in his concept of the 'third industrial revolution' based on renewable energies. In his 2012 book he identifies what he calls 'five pillars' of this next industrial revolution, specifically: 1) a shift to renewable energies; 2) converting buildings into power plants (e.g. by solar panels); 3) introduction of hydrogen and other energy storage technologies; 4) smart grid technology (internet-based); and 5) plug-in, electric, hybrid and fuel cell transportation. Until recently, such views were considered utopian. Such a perspective is now supported by the emerging literature regarding renewables as providing an anticipated 100% replacement for fossil fuels within a reasonably short time frame, such as by around 2030 (e.g. Jacobson and Delucchi (2011); Scheer (2012)). Rifkin's 'five pillars' are undoubtedly fundamental features of the current shift. Ayres and Ayres (2010) add the essential element of a shift to energy-efficient and energy-saving innovations as an equally important feature of this fundamental transformation. These perspectives are given strong support by the US National Renewable Energy Laboratory in its recent report where it is stated that "The central conclusion of the analysis is that renewable electricity generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050 while meeting electricity demand on an hourly basis in every region of the United States" (Mai et al 2012: iii).

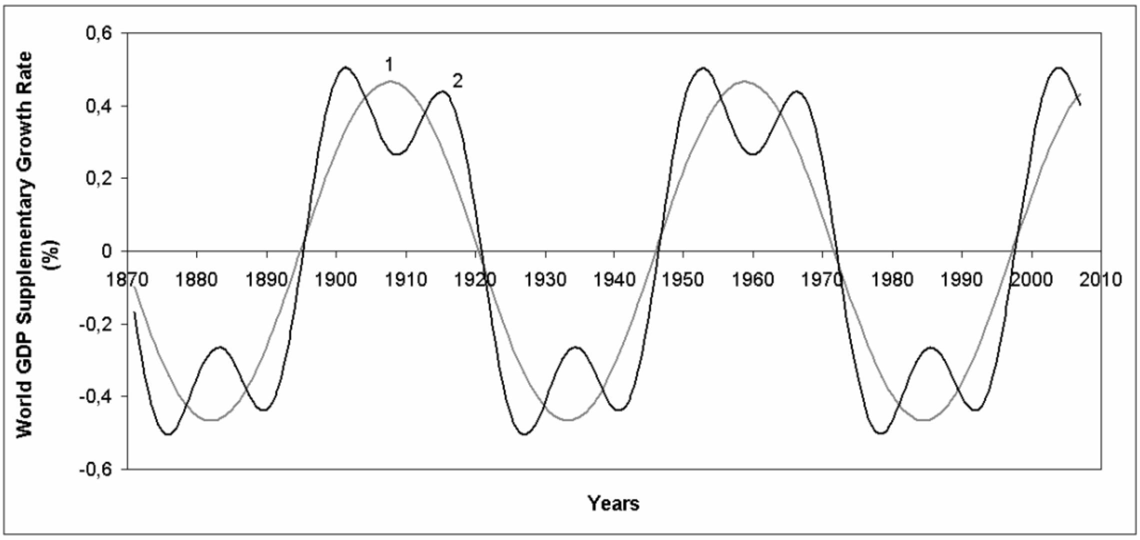
In general terms, the notion of 'cleantech' as developed by Pernick and Wilder (2007) applies to the characteristics of the 6th TEP. Some forward-thinking consulting firms are also engaging with these issues. Merrill Lynch sees the shift to cleantech as involving both renewables and biotech, or more generally, the industrialization of natural resources (Milunovich and Rasco 2008). Likewise the Allianz report of 2010 views the sixth paradigm as being driven by clean tech, biotech, nanotech and 'holistic health care' – but the case is not made that these may be viewed as fundamental carrier technologies (not yet). Thus these contributions focus on contingent features of the renewable energies technology 'surge' and do not (as yet) add theoretical depth to the notion of TEP already formulated by neo-Schumpeterian scholars.[2]

The situation in 2012/13

An interesting empirical starting point is provided by the spectral analysis of long waves conducted by Andrey Korotayev with his collaborator Sergey Tsirel. These Russian scholars analyze the current situation as one where there are trends moving in one of two different directions. The background to this analysis is provided by spectral analysis of the third, fourth and fifth waves, as reproduced in Fig. 1 below.

Fig. 1. K-wave pattern revealed by spectral analysis, 1870-2010

[2] For studies of the complexity of the transition under way, see for example Foxon, Hammond and Pearson (2010) for a study focused on UK electricity generation, and Eriksson and Weber (2008) for a strategy of adaptive foresight designed to navigate the complexity of policy landscapes. Van den Bergh (2013) provides insight into the interactions between environmental and climate innovation, with emphasis on the limitations of policies targeted at just one feature.



Source: Korotayev and Tsirel (2010), Fig. 3-A, showing the first harmonic (wave 1) and the sum of the first and third harmonics (curve 2) with the world war and interwar values replaced by geometric means.

Korotayev and Tsirel interpret their reconstruction of the long waves, utilizing their spectral analysis, as revealing a strikingly consistent long-wave pattern (with a shortening of the wave period closer to the present time). The current period looks like the peaking of the fifth K-wave, and could indeed be such; in this case the global financial crisis of 2008-09 would be taken as the signal for the next downturn. But the authors offer an alternative reading – namely that the current period may be interpreted as a temporary depression between two peaks of the next upswing. By extrapolation, they predict that such a temporary upswing may begin around 2012-2013 (i.e. now) and could reach its maximum by 2018-2020. The driver of such a temporary upswing is left unsaid in their paper. They discount the role of communications and IT, which are thought to have exhausted their reserves of fast growth (i.e. bringing to an end the 5th TEP). One factor that they do point to is the acceleration of global convergence (of East on West) through ‘acceleration of the diffusion of the extant high technologies to the populous countries of the World System periphery’ – of which China would have to be taken as prime exemplar, and in which green technologies would have to be identified as prime candidates. While expressing the appropriate caution, this does in fact seem to be the authors’ implied candidate.[3]

[3] There is also strong evidence that the more obvious interpretation, namely that world GDP has just gone through its K-wave peak, is also plausible – particularly if the world falls into a ‘double dip’ recession in 2012-13. The authors conclude: ‘At the moment it does not seem to be possible to decide finally which of those two interpretations is true’ (2010: 19-21).

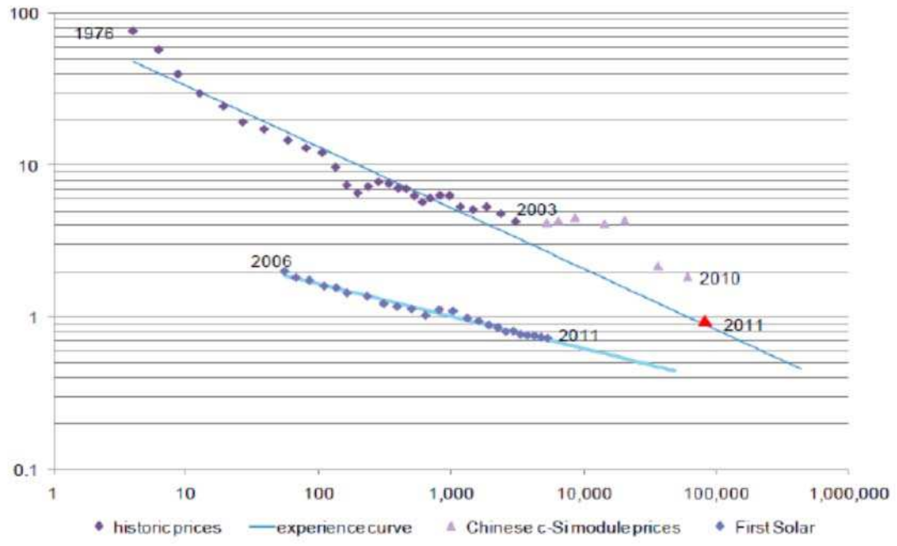
The characteristics of a new TEP – and their application to renewables and cleantech

In the Freeman-Perez argument, a novel TEP is characterized by three defining criteria: 1) changes in cost structure, with the emerging technological regime enjoying strong and increasing cost advantages; 2) expanded perception of opportunity spaces, creating multiple entrepreneurial opportunities for the application of the emergent bundle of technologies; and 3) new organizational models, where the new is better fitted to the emergent technologies and generates massive gains in terms of efficiency over those linked (or constrained) by the dominant paradigm. For the purposes of this paper, let us take these characterizations as definitive: 1) falling costs; 2) costs lower than the incumbent technology; and 3) pervasive effects.

In the case of renewable energies or clean tech, one can make the case that two out of three of these fundamental conditions are satisfied – falling costs and pervasiveness, while costs lower than incumbent fossil fuel sources are close, but not yet achieved (‘grid parity’). As soon as they are priced at or below fossil fuel sources, which should occur by around 2015, one can anticipate a speculative financial bubble to lead to a period of sustained industrial investment in renewables and cleantech, as carrier of the sixth paradigm.

On the issue of **falling costs**, the uptake of REs is driven by a learning curve (or experience curve) of costs that are falling drastically. The case of solar PV power generation is shown in Fig. 2, while wind power is similar if somewhat less intense. By contrast, costs for all the fossil fuel and nuclear incumbent energy producers are rising, and can be expected to continue rising as the challenges and risks of securing supplies continue to mount while demand intensifies (Bazilian et al 2012).

Figure 2. PV module experience curve, 1976-2011



Source: Bazilian et al (2012), Fig. 1

In this chart, the overall experience curve is shown in the upper blue line, indicating that costs have been falling at an annual average rate of 45%, and had reduced to the **long anticipated point of $1 per watt** by the end of 2011 -- bringing solar photovoltaic (PV) power within the range of every country. This provides a sound foundation for global diffusion of the next TEP.

On the **pervasiveness** of the carrier technology (and the generation of entrepreneurial opportunities), the REs paradigm shift is already well advanced. The entrepreneurial and business openings are being created in the immediate sector of RE generation systems themselves (wind power generators, solar PV generators, concentrated solar power towers and linear arrays) and the supply chains that are created to feed these new end-products; and then in associated business activities that utilize renewable energies as priority, such as electric vehicle charging systems and green buildings in cities; and finally in the range of totally new activities associated with REs such as new and smart grids, new metering systems, new transport systems such as EVs and their associated infrastructure (charging systems), new industrial heating systems utilizing concentrated solar power, new designs for ‘green cities’ – and so on.

For each new paradigm, Perez sees the evolution and interaction between productive and **finance capital** as follows: ‘The world of finance itself is amongst the pioneers in adopting the new paradigm, especially in organisation, equipment, transport and communications. It rapidly invents, learns and diffuses new ways of providing venture capital, of attracting new investors and new capital to the market and of leveraging, handling, hedging and spreading risk' (2009: 781). Specifically in the case of REs and low-carbon technologies in the 2010s, one may see the role of finance for example in inventing new eco-targeted bonds (green bonds, or climate bonds) which can be expected to attract major institutional investors and to aggregate projects to the scale of index-oriented investment (Mathews and Kidney 2010).

At the same time it is necessary to acknowledge that the resistance posed by corporations and institutions associated with the 4th TEP (fossil fuels and centralization) is fierce, aptly characterized as 'carbon lock-in' (Unruh 2000) – and is actively slowing the diffusion of renewables and cleantech as a result (Sovacool 2009; Negro et al 2012). The sources of resistance range from outright subsidies paid to the incumbent energy producers (which according to the International Energy Agency amount to billions of dollars annually), to policies and practices designed by fossil fuel and nuclear industries designed to perpetuate their position, and even encompassing outright legal bans such as the laws that forbid connection by independent power producers to the grid that hold in some US states (Ayres and Ayres 2010).

Despite these difficulties, the current surge in renewable energy and cleantech investments and capacity additions is real and is having real sociotechno-economic effects – particularly in China and Germany where its adoption is most intense.[4] It is the harbinger of a sixth TEP, with REs as driving factor, where we see the new RE-driven TEP emerging from its gestation phase and entering the installation phase, where finance capital is more daring than productive capital. If Perez is correct in her formulations, we can expect this RE paradigm to blow out into a speculative financial bubble, that might be dated (according to previous sequencing) sometime in the period 2015-2020. That gives several more years of booming RE investments, with RE systems moving along a logistic industrial trajectory to become, by the time of the bursting of the bubble, the new 'conventional wisdom' in energy generation. This would pave the way to a true 'deployment' phase of renewable energies and energy-service innovations, driven by productive capital. Such a perspective bears striking correspondence to the findings of Korotayev and Tsirel in identifying a 'secondary surge' in investment at the turn of the fifth K-wave, which they date from around 2012/13 to the period

[4] Investments in renewable energies reached US$257 billion in 2011 – over a quarter of a trillion dollars (BNEF 2012). Large as this seems, it is as yet small compared to the trillions that bodies such as the International Energy Agency assert will be needed.

around 2020. This is a remarkable coincidence of neo-Schumpeterian scholarly views, albeit starting from different premises and using different methodologies.

Organizational features of the new 6th TEP

Freeman and Perez devoted much effort to drawing out the ‘organizing principles’ of the emergent 5th TEP in the 1980s, and it is important to make a comparable effort now for the emergent 6th TEP. These principles may be characterized as those which favour the emergence of RE and cleantech systems and which clash with those developed during the previous fourth and fifth TEPs. Amongst these contingent, emerging organizational and industrial design principles we would have to include the following.

(1) A shift to renewable energies and enhanced efficiency as dominant energy paradigm

As against the fossil-fuelled and centralized energy systems of the 4th TEP, carried over into the 5th epoch, where resource abundance is taken as a given and energy efficiency is the least consideration, the generation and husbanding of energy will be the prime factor in the emergence of the 6th TEP. Renewables of all kinds will be tapped, through sophisticated technologies developed for the purpose, such as concentrated solar power with molten sale technology, that is already operational in several plants (e.g. Gemasolar in Spain) and which offers reliable, baseload power for close on 24/7 dispatchability at costs that are rapidly falling and low resource intensity (Piemonte et al 2011). There are also new systems for improving efficiency, such as combined heat and power (CHP) are already being widely deployed in Europe and elsewhere. Prospects for 100% reliance on renewables are now being discussed (e.g. Jacobsson and Delucchi 2011) and taken seriously by government agencies (e.g. the US NREL: Mai et al 2012). While the price of oil has been the determining economic influence in the fossil fuel era, the price of renewable energy is now emerging as dominant economic influence in the new era – shaping investment trends in lead countries such as Germany and China (Mathews and Tan 2013).

(2) A shift to resource circulation as dominant materials paradigm

A complementary shift away from the linear resource flows of the 4th and 5th TEPs is also underway. A fundamental feature of the cleantech shift is reducing the flow of resources, to curb the prevalent linear model where virgin resources are extracted at one end (from nature) and waste resources are dumped at the other end (again into a sink called nature). In Germany and some European countries an alternative approach to resource management known as "cradle to cradle" (C2C) has been developed (McDonough and Braungart 2002), while in China an even more radical process of linking industrial waste flows to alternative uses as industrial inputs is actively promoted under the rubric of the Circular Economy and its promotion law (see e.g. Mathews and Tan 2011). Improving resource efficiency through recirculation is just as important a feature of the new TEP as tapping sources of renewable energy.

(3) Application of IT to power generation as key driver (smart grid)

While the fossil fuelled energy systems were laid down as part of the 4^{th} TEP, the emergence of the 5^{th} paradigm opened the way for IT-based systems, which have been encompassing the globe for the past three decades. But IT applications stopped short of energy systems. It is only with the rise of smart grids, designed to accommodate a rising proportion of renewable energy generation, that IT comes to be applied directly to the energy system and completes the IT revolution begun under the 5^{th} TEP (Moslehi and Kumar 2010). If governments make explicit commitments to promote renewables, and in particular to promote standards for IT-enhancement of electric power grids, then they are paving the way for successful emergence of the 6^{th} paradigm.

(4) Decentralization and competition in power generation

The fossil fuelled and centralized power generation features of the current energy system emerged as part of the 4^{th} TEP shift, and were not shifted by the emergence of a 5^{th} TEP that made little contact with energy systems. Now the application of IT to energy systems, through such applications as the smart grid, creates the possibility for a radically different organizational structure in countries where power generation has been decentralized and new, independent power producers allowed to connect to the grid. In Germany the contribution of the four oligopolistic power generators (E.on, RWE, EnBW and Swedish Vattenfall) has been drastically reduced, while the role of local coops, municipal authorities and independent power producers (IPPs) such as farmers, has expanded steadily, through the workings of the feed-in tariff system. In Germany this transformation of the energy system is called the *Energiewende* (Morris and Pehnt 2012; Davidson 2012) and it corresponds almost exactly to the lines of development of the 6^{th} TEP.

(5) Global free trade in cleantech products

Behind the success of the transition to a 5th TEP lay a little-known global trade agreement, termed the Information Technology Trade Agreement (ITA) endorsed by a group of countries in 1996 and then adopted by the WTO. It underpinned successive reduction in tariffs on IT products, and underwrote the global expansion of the market for IT products.[5] Exactly the same policy is called for to drive the adoption of a cleantech-based 6th TEP – as called for by think tanks such as the ITIF.[6] An important step towards such an agreement was the adoption by APEC countries in 2012 of a commitment to reduce tariffs on a range of cleantech goods ("environmental goods") to less than 5% within five years (Nimubona 2012).[7]

(6) Creation of international market for renewable electric power

The basic resource of the 4th TEP has been oil, which is traded globally in a market that is unencumbered by tariffs and legal restrictions (but subject to strict standards). No such favourable circumstance exists as yet for the basic carrier of the 6th TEP, which is renewable electric power. There are proposals for international carriage and interconnection of renewable electric power, such as the Desertec proposal linking North Africa with Europe, or the Asian Super Grid proposal which would link wind and solar farms in Mongolia with consuming industries in China, Japan and Korea in the first instance and further afield in South Asia in the longer term.[8] While appropriate caution is warranted (Lilliestam and Ellenbeck 2011) adopting the perspective of emergence of a 6th TEP shift would facilitate the dismantling of trade barriers holding back such international power inter-connections.

(7) Creation of novel financial instruments such as green bonds

No great transformation is feasible without the participation of the finance sector. Any notion that it can be engineered by public finance alone is a fantasy. Finance is indeed the engine

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[5] As stated on the WTO website, "The Ministerial Declaration on Trade in Information Technology Products (ITA) was concluded by 29 participants at the Singapore Ministerial Conference in December 1996. The number of participants has grown to 70, representing about 97 per cent of world trade in information technology products. The ITA provides for participants to completely eliminate duties on IT products covered by the Agreement. Developing country participants have been granted extended periods for some products." See: http://www.wto.org/english/tratop_e/inftec_e/inftec_e.htm

[6] See the ITIF policy call "WTO should create a clean technology agreement modelled on the ITA" 2012, at: http://www.itif.org/content/wto-should-create-clean-technology-agreement-modeled-ita-combat-green-mercantilism

[7] The APEC countries signing up for this commitment include China, the US, Japan and Australia.

[8] See the posting by John Mathews to *Asia Pacific Journal: Japan Focus*, on "The Asian Super Grid" (2012), at: http://www.japanfocus.org/-John_A_-Mathews/3858

room of capitalism – to borrow one of Schumpeter's favourite phrases. And the heart of finance is the system of bonds – the capitalist instrument of credit *par excellence*. The financial system has evolved rapidly since the early *prestanze* and *prestiti* created by the Italian city states Venice and Florence in the 13th century, and which underpinned their commercial success. These markets are the direct antecedents of the bonds markets of today; they are the origin of the modern notion of *securitization*. Now what is needed are new financial instruments that can channel investments towards cleantech and renewable projects. The World bank and International Finance Corporation have pioneered such instruments, in the form of green bonds, which have been a way of testing the waters. In early 2013 the Korean Export-Import Bank stepped forward to issue a US$500 million green bond; it was the first national bank to do so. The bond issue was over-subscribed nearly fourfold, at US$1.8 billion. This points to unsatisfied demand on the part of institutional investors for safe, medium-term cleantech bonds, who are said to draw on tens of trillions of dollars controlled by institutional investors (Croce, Kaminker and Stewart 2011). At such financial scale they would be able to ensure a successful transition away from a fossil fuels dominated paradigm.

These seven features are emphasized with a view to outlining the new organizational logic that promises to underpin the emergence of the 6th TEP – a logic based on renewability, resilience, decentralization, open competition and resource husbandry. This is a logic opposed to resource profligacy, centralization and oligopoly, which have been the hallmarks of the fossil fuel and nuclear era. The point of bringing out these organizational features is to emphasize the main lines of development where entrepreneurial initiative can be expected to reap rewards and policy can facilitate the process of transition, as opposed to upholding the status quo.[9]

Policy implications of a new 6th TEP shift

We may now draw together the implications for policy arising from this convergence of theoretical views on the organizational characteristics of the emergent TEP. It is clear that there will need to be a strong role for the state to play in driving economies onto new, sustainable trajectories. A strong state role will be needed to overcome the resistance of the incumbents; to pave the way for the new; and to create competitive industrial sectors to bring

[9] Zysman and Huberty (2011) make a similar point in arguing that GG considerations need to develop beyond religion to reality – meaning that they must engage with the world as it is.

the processes unleashed by the 6th TEP to fruition. Five major policy conclusions may be drawn – based on the working assumption that a complete transition to a renewable energy and resource-efficient economy may be feasible within the next two decades.

1) Creative destruction to be allowed to work – contra 'carbon lock-in'

The essence of Schumpeter's view of the workings of capitalism is that it is uniquely characterized by creative destruction, by which the old is destroyed to make way for the new. But in practice the incumbents do everything in their power to block the process; it is frequently allowed to operate only through forceful intervention by the state, upholding processes of fair competition and correcting for subsidies enjoyed by incumbents. In the case of the energy industry, the fossil fuels sector has a 'lock' on industry structures and pricing, backed by widespread subsidies (such as exploration and drilling tax breaks) that is well expressed as 'carbon lock-in' (Unruh 2000; Unruh and del Rio 2012). The first policy implication of adopting the perspective of an emergent 6th TEP shift is to insist that creative destruction be allowed to proceed, through unravelling the subsidies applied to fossil fuels and giving new renewable and cleantech firms the tax concessions and support they need to break the existing carbon lock-in. Active promotion of presently small market niches, that have the potential to become major new industries, would be needed. The governments that adopt such a perspective are the ones that can expect to see firms advancing the new 6th TEP most effectively.

2) Renewables and cleantech as the preferred option

Based on the dominance of renewables and cleantech in the emergence of the 6th TEP, the best policy choice for governments is to go with this trend, and adopt support for such technologies as their prime contribution. Apart from dismantling support for fossil fuels and nuclear, this means creating and expanding markets for renewables, such as through public and military procurement, and the setting of market mandates (as practised very effectively by Brazil for biofuels). Strong policies along these lines would be needed to overcome incumbent inertia.

3) Resource recirculation as preferred option

Likewise the shift to resource husbandry needs to be backed by strong state intervention in the form of new laws (where China's Law for the Promotion of the Circular Economy is the outstanding candidate) and new practices by public authorities (again in China's case the trend towards locating industry in new eco-industrial parks where resource and energy sharing is emphasized).

4) Trade and competition to be promoted

The centralized, oligopolistic features of the fossil fuel era need to be dismantled to make way for the new decentralized and competitive features of the new – as exemplified by the rise of independent power producers in Germany as part of the *Energiewende*. Global trade in renewable fuels and in renewable electric power need to be encouraged by deliberate policy intervention, to create the equivalent of the free trade in oil that characterized the 4^{th} TEP and free trade in IT that characterized the 5^{th} epoch.

5) Taxes on pollution and virgin resources rather than on labour or capital

Taxation in earlier technoeconomic paradigms has been based on labour and capital as well as trade (in the form of tariffs, excise and duties). To facilitate the transition to a new TEP, the burden of taxation needs to shift to sources of pollution, such as carbon-intensive industries and fossil fuel consuming sectors. Such a transition is already underway, with Germany applying considerable gasoline taxes (along with other countries in Europe) and now swinging towards what is called 'environmental taxation' (Agnolucci 2009), and China likewise taking steps to shift the burden of taxation away from labour and capital towards activities that lead to pollution (Hu 2006; 2011). These trends can only be expected to continue and strengthen.

Most significantly, an economy characterized by the organizational principles of the 6^{th} TEP and the set of policies outlined above, would be expected to keep within the boundaries of its ecological limits. Its default position of working off renewable energies and recirculating resources would trend toward the economy working within ecological cycles – and any deviations would be spotted by the authority vested with this responsibility, with corrective actions (taxes, limits or penalties) being implemented. Thus the 6^{th} TEP may be viewed as an important step towards the reconciliation of ecological and economic principles.

Concluding remarks

The trajectory for the REs paradigm in the coming decades is likely to be one of total replacement of conventional (fossil fuelled and nuclear) power sources by those based on decentralized generation and distribution of renewable sources. But equally the new TEP (or energy industrial revolution) may be frustrated and blocked by powerful forces of industrial inertia and 'carbon lock-in'. The future, of course, is far from determined. In outlining an interpretation of the patterns of the past, as seen through the lens of technoeconomic paradigm shifts, this paper is not of course succumbing to any notion of technological determinism. Innovators and entrepreneurs will do what they do, and act as they act, according to their own judgments; but an understanding of the patterns of the past may help in analyzing the reasons that their ventures may succeed or fail. Policies need a context, both to be explicated and to be effectively implemented.

The perspective a 6^{th} TEP shift is salutary for a number of reasons. It brings the policy issues involved into stark relief, and clarifies why feed-in tariffs are superior as a means of promoting new, decentralized independent power producers to alternatives such as renewable portfolio standards (which apply only to existing power producers and thereby leaves the structure of the power generation sector intact). It clarifies the point that what is being discussed is not just an 'environmental' policy (albeit one with profound environmental and ecological consequences) but one that engages with the entire economy and with the whole of government (as in the case of the Green Growth strategy pursued in Korea and elsewhere). Finally, and not the least important aspect, the framing of the current transition as one that involves a techno-economic paradigm shift, driven by Schumpeterian dynamics, opens up for young new-Schumpeterian scholars new horizons of policy-relevant research. Such a framework invites scholars to engage with the big issues of the day such as mitigation of global climate change, East-West convergence and the rise of China as an industrial super-power, and the dynamics of technological change in new industrial sectors such as concentrated solar power, wind power, photovoltaics and electric vehicles.

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