The Comparative Advantage and Relative Impact of Asian Emerging Economies in Low Carbon Energy Technological Systems

Chan-Yuan Wong*, Zi-Xiang Keng, Zeeda Fatimah Mohamad, and Suzana Arif Azizan

Chan-Yuan Wong
*Corresponding Author
Email: wongcy111@gmail.com

Affiliations:
Chan-Yuan Wong, Zeeda Fatimah Mohamad, and Suzana Arif Azizan
Department of Science and Technology Studies,
Faculty of Science, University of Malaya,
50603, Kuala Lumpur, Malaysia

And

Zi-Xiang Keng
UM Cares
University of Malaya Environmental Secretariat,
50603, Kuala Lumpur, Malaysia

Yogyakarta, Indonesia.
15-17 Sept. 2015

The Comparative Advantage and Relative Impact of Asian Emerging Economies in Low Carbon Energy Technological Systems

Abstract

This paper highlights the specificities of the patterns of low carbon energy technological innovations in selected Asian emerging economies. China and the members of ASEAN-4 (Thailand, Malaysia, Indonesia and the Philippines) are included in this analysis for their identical structure of developing economies. We outline a synthetic framework to cluster the technologies with similar characteristics and analyse the changes of these characteristics over time to elucidate the scope of sectoral composition and specialisation of the selected economies, in order to understand the relative impact of science-based low carbon energy technologies on the niches of technological excellence. The findings show that China was keen to pursue its diversification strategy and develop its capability in low carbon energy technologies since the turn of the millennium. However, China has been gradually losing its momentum in more traditional areas like biomass, hydroelectric power, natural gas and fossil fuels. The ASEAN-4 economies, on the other hand, are showing interest in building a number of niches of technological excellence. This highlights a contrasting relative technological advantage between large and smaller economies. Our findings also indicate that many of the low carbon technologies in selected economies have yet to attain strong scientific grounding for development. The findings of this paper are expected to provide some insights into low carbon energy technological development of emerging economies, and be useful for other developing economies to establish their strategic moves for energy industrial development.

Keywords: Low Carbon Energy Technology, Comparative Advantage, Impact, Patents, Emerging Asian Economies

1. Introduction

The East Asian economies' experience in low carbon energy technology catching-up emerged to be accompanied by a coupling of different semiconductor manufacturing and servicing industrial activities [1]. The accumulated technical knowledge in the semiconductor industry appears to have laid a strong foundation for many newly industrialized economies such as South Korea and Taiwan to establish a pre-condition for the emergence of low carbon energy technologies [2]. As low carbon is seen as a field that will concord with next wave of technologies in the region, many Asian economies invested heavily in their targeted low carbon energy technologies such as solar photovoltaic and LED (Light-Emitting Diode). They attempt to reconfigure a new structure of innovation systems that will build new niches for their global and domestic markets.

While many newly industrialized economies have managed to attain new niches in the global low carbon energy technological chain, many policy makers in developing economies express serious concerns about the sustainability and competitiveness of their industries. The concerns revolve around *what* comparative advantage their economy has in the technological global value chain, and *which* technology is to be targeted so that it will make a positive impact on the global low carbon energy market demand. Thus, understanding the process of creative accumulation has been the central effort of many technological and innovation scholars since Schumpeter [3]. Many scholars [4, 5 and 6] recognised the importance of cumulative learning processes (that are basically driven by the competencies of an industry) to the emergence of new high-technology sectors. While some [7, 8 and 9] delved into different aspect of competitiveness and various economic indicators to depict the position and technological capabilities of an economy, Nesta and Patel [6] researched into patenting activities to understand and stylise the national and corporate patterns of technological accumulation. Lee and Lee [10] and Wong et al. [11] employed patenting data to map the patterns of innovation in energy technologies.

While the literature on energy technological innovation informs us on how to stylise the pattern of technological accumulation and the generic patterns of low carbon innovation, a systematic approach – with a dynamic perspective to mark the commonalities (and differences) amongst the developing economies in national patterns of low carbon energy technology accumulation and in both aggregate and in sectoral composition and specialisation – is still severely lacking. In what follows, we will highlight the specificities of the patterns of low carbon energy technological innovations in selected Asian emerging economies. China and the members of ASEAN-4 (Thailand, Malaysia, Indonesia and the Philippines) are included in this analysis for their identical structure of developing economies. These economies share many similarities in term of income structure, science and technology policy options, and as latecomer economies; they appear to have gained substantially from the composition of world market demand [12]. This paper attempts to expand the findings of Lee and Lee [10] and Wong et al. [11] by incorporating the scope of sectoral composition and specialisation of Asian emerging economies and understanding the relative impact of science-based low carbon energy technologies on the niches of technological excellence. We outline a synthetic framework to cluster the technologies with similar characteristics and analyse the changes of these characteristics over time. The findings of this paper are expected to provide some insights into low carbon energy technological development of emerging economies, and be useful for other developing economies to establish their strategic moves for energy industrial development.

2. Literature Review

Much of the contemporary writing in energy-related studies has been devoted to elucidating the dynamics of low carbon energy science and technology. The "technological development trend" research is gaining ground in both academics of energy technological innovation and policy makers who aspire to lay an institutional platform that is conducive for technopreneurs to produce and distribute low carbon energy technology.

Our reading on the low carbon energy technology development studies revealed a number of themes that correspond to the perspectives of Schumpeter [3] and Lundvall [13] on innovation capabilities and innovation system and Jaffe and Trajenberg [14] on knowledge network. The themes include Albino et al. [15] on eco-innovative activities, Choe et al. [16] and Duan [17] on productive network structure in energy technologies and Wong et al. [11], Li et al. [18], Mueller et al. [19], Wonglimpiyarat [20] and Corsatae [21] on capabilities for low carbon energy technologies. The use of publishing and patenting statistics as proxies for low carbon technology is appeared to be common in their analysis. These papers highlight the national concentration of different low carbon energy technological activities and offer developing economies a guide to transform an existing undesirable technological landscape to a more functional innovation system based on multiple transition mechanisms. The mechanisms include subsidies and supports for adoption of low carbon technologies, support for R&D learning, network formation for new technologies, information provision through various channels to attract investment in new technology, and so on [20, 22-24].

The innovation system and knowledge network models emerged in the literature to be rich and have a strong foundation as an analytical tool for analysis at the technological level. Building on the studies on the technological change and dynamics of innovation system of various economies, Albino et al. [15] and Choe et al. [16] studied and discussed the characteristics of the low carbon energy technological development. Lee [25] depicts the dynamics of energy technology innovations to present possible scenarios for the evolution of energy technology. Patent is used in these studies as proxy for technology capability. Duan [17] on the other hand, studied the cooperation patterns in low carbon energy related R&D with a special focus on the co-publication activities. While two cooperative entities, university and public research organization, are highlighted in Duan's analysis, industry witnessed itself to have gradually emerged as productive partner in co-publishing activities.

The publication and patent statistics are found useful and effective in these studies in highlighting the path of technological evolution patterns in the field of low-carbon energy. Many of these studies appear to have particular interest in the cases of developed economies. While the findings unveiled the progress of energy technology, we noted that a systematic approach to the understanding of the technological accumulation patterns in the emerging economies, such as China and ASEAN economies, with regard to the comparative advantage in a dynamic perspective is still severely lacking. In addition, the relative impact of science on low carbon energy technologies in the context of developing economies remained undiscovered. To the best of our knowledge, mapping the low carbon energy technologies with similar characteristics and analyse the changes of these characteristics over time and understand the relative impact of science-based low carbon energy technologies on the niches of technological excellence have not been considered in the literature. The comparative advantage of energy technologies and the impact of science-based low-carbon energy technologies are remained to be explored. Therefore, we see a need to assess the dynamics of low carbon energy technologies. The assessment is important, on one hand to validate and ensure the development potentials of low carbon technologies in the emerging economies, and on the other hand to inform the literature of energy technological system an account of the dynamic innovation process in the context of developing economies.

The following sub-sections are organized with an attempt to bridge the gaps of the literature. Section 3 on methodology of the study discusses the conceptual framework. The findings and analysis are discussed in section 4. Section 5 concludes.

3. Methodology

Following Pavitt's pioneering work [26] on the patent statistics to map the nature of technological accumulation, many studies had contributed quantitative evidence to elucidate the accumulation trajectories of science and technology of many emerging economies. While some scholars [5 and 6] provide indications of *which* economies specialise in *what* leading edge technologies, others [10 and 27] elucidate what technologies would likely lead a few opportunities in global technological value chain. Their studies employed patent statistics to construct proxy variables for technological innovation and to quantify the change in technology and national specializations in the global value chain. The literature has made heavy use of the total count of national applied and granted patents as proxy for the technological capability of an economy; the intensity of national patents in specific fields as proxy for the technological competitive advantage of an economy; and patent citations as proxy for both the intensity of knowledge flow and value in the market or society. The patent statistics have been useful. While many measures of research and technological activities (e.g. expenditure of R&D or scientific publications) rarely indicate direct economic values, benefits or profit, patent statistics can be used to represent the codified part of technological innovation that reflects the interest in commercial exploitation of a new technology.

Existing studies in the literature appear to lack the documentation of sectoral specialisation of emerging economies and fail to understand the relative value of science-based low carbon energy technologies. Therefore, we believe we can make a worthy contribution to enrich the literature of innovation systems and low carbon energy technology accumulation of developing economies. Drawing upon the findings of Wong et al. [11], this study extends the analysis with the aim to analyse the sectoral specialization (proxied by patents) in selected emerging economies in Asia. We employed the keywords search used in Wong et al. [11] to identify low carbon energy related patents. We record the annual number of applied patents of the selected Asian economies from 1980 to 2012 from the Patent Cooperation Treaty (PCT of the World Intellectual Property Organization) database. The keywords are according to the line of technology of different fields (see Table 1).

Table 1: Indicative List of Technologies Classified under Low Carbon Energy

Energy Service	Category	Technology (Keyword)
Electricity Production	Renewable	• Combined heat and power • Tidal energy • Wind turbine • Geothermal energy • Solar energy • Photovoltaic • Solar thermal • Biomass energy • Biogas • Energy storage • Hydro energy • Electricity storage
	Fossil fuel	• Fossil fuels (all types) • Natural gas • Electricity storage
Demand-side Management System	Energy Saving	• Energy efficiency • Building ventilation • Building insulation • Light tubes • LED

Source: [11, p. 5]

We then follow Nesta and Patel's approach [6] to formulate the index of national comparative advantage in low carbon energy technologies. Revealed Technological Advantage (RTA) index can be depicted as:

$$RTA\_X_{it} = \frac{PAT\_X_{it} / \sum_i PAT\_X_{it}}{PAT_{it} / \sum_i PAT_{it}} \quad (1)$$

Where:

- PAT_X_{it} denotes the number of applied patents of *X* economy in technological field *i* (see Table 1) of year *t;* and
- A value above unity (above 1) indicates a field of relative strength, while a value below unity (below 1) indicates a field of relative weakness.

As typical developing economies in the race to secure comparative advantages in low carbon technological value chains, China and ASEAN member economies are facing the urgency to transform their productive routine in duplicative imitation into a structure that supports science-based technological innovations. They have initiated many science and technology programs to institute a routine that allows co-evolution between scientific activities and industrial technological innovations. In this study, we are interested to explore what position in technological value chains these economies attained, and what science-based technologies have been targeted in these economies to create a positive impact to their market and society. We employ the number of science-based backward citations to patents (patents that cite scientific related literature) extracted from the US Patents and Trademark Office (USPTO) database in order to frame the Relative Impact Index (RII) [6 p. 538] and study the relative impact of science on technology. Positing an intensity value of backward citation as a nominator of RII function enables us to identify the technologies that are dependent on the spillover of scientific knowledge for development, and will subsequently allow us to highlight the relative impact of science-based technologies on the overall value of technologies. RII is therefore defined as follows:

$$RII\_X_{it} = \frac{BC\_X_{it} / \sum_i BC\_X_{it}}{PAT\_X_{it} / \sum_i PAT\_X_{it}} \quad (2)$$

Where:

- *BC* indicates the number of science-based backward citations to patents received by country *X* in technology field *I*; and
- A value above unity implies a field of relative high impact of science on technology.

To provide a context for understanding the scope of sectoral composition of selected economies, we established a map (Figure 1) that enables us to visualise the comparative advantage of selected economies in low carbon energy technologies. We plot each technology on a 2-dimensional map, with RTA along the X-axis and patent share along the Y-axis. The lower left quadrant represents the low technological advantage position, whereby the technologies clustered under this quadrant have not been a priority of an economy to secure a specific global market position. The technologies belonging in the upper left quadrant may have attained a specific global market position due to competencies of an economy that were acquired over a long period time, but such a position has low correlation with the change of technological advantage over other technologies. This may be attributed to the relatively large size of the field that ultimately led to the failure of an economy to gain a comparative advantage over other economies. Those technologies in the lower right quadrant exhibit their niche advantage position for an economy in relatively small fields, and those in the upper right quadrant indicate their distinctive technological advantage position of an economy over others whereby such a position has enabled an economy to extract rent from its patents' portfolio.

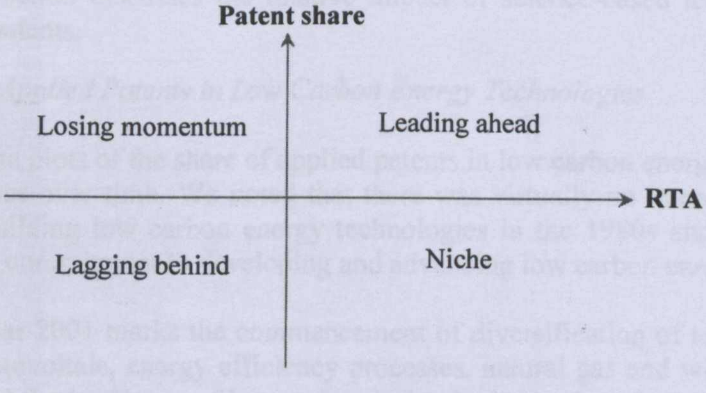

Figure 1: A Classification for Low Carbon Energy Technological Profiles

To map the relative impact of science-based low carbon energy technological research on the niches of technological excellence, we developed another map that allows us to cluster each technology into four groups. The lower left quadrant of Figure 2 represents a position in which the technologies have no direct linkages with scientific knowledge, and thus gained limited value in the market and society. The upper left quadrant represents a position in which the impact of technological innovations of an economy has little correlation with the science-based technologies. The lower right quadrant describes a position in which science-based technologies have made little impact on the overall value of technologies, and the upper right quadrant elucidates a position of high correlation between science-based technologies and overall value of technologies in the market and society.

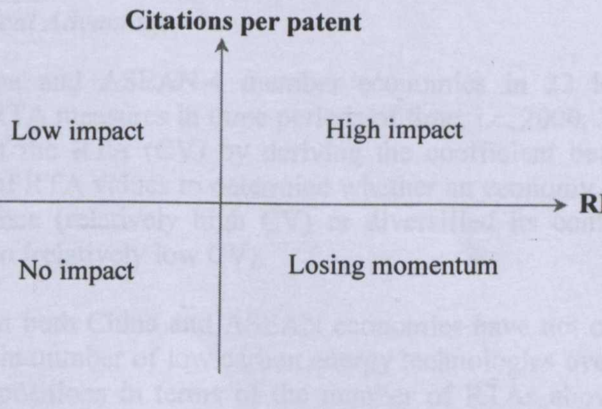

Figure 2: A Classification for the Impact of Science-based Low Carbon Energy Technologies

4. Results and Analysis

This section focuses on cross-economy similarities and highlights the differences in low carbon energy technology capabilities. The common share of low carbon energy related patents of selected economies is firstly discussed. The comparative advantage of selected economies is discussed in the following sub-section. Comparisons are made between China and ASEAN member economies. Malaysia, a member country of ASEAN that is known to have committed to building science and technology capabilities since the 1980s [28], is used as case study to reflect the changes of technology targets in ASEAN economies. The subsequent sub-section discusses the relative impact of science-based technologies on the overall value of patents.

4.1 The Share of Applied Patents in Low Carbon Energy Technologies

Figure 3 shows the plots of the share of applied patents in low carbon energy technologies for selected economies over time. We noted that there was virtually no interest in the selected economies for building low carbon energy technologies in the 1980s and 1990s. The year 2000 witnessed a commitment to developing and advancing low carbon energy technologies.

The following year 2001 marks the commencement of diversification of technologies. LED, solar energy, photovoltaic, energy efficiency processes, natural gas and wind turbine appear to have dominated the landscape of low carbon technologies in the selected economies. Light tubes, geothermal, and building insulation may emerge in the early 2000s as complementary assets for the development of core industries.

The share of two technologies, LED and energy efficiency processes has been remarkable.
We believe that the high technology development focus of LED is attributed to the interest in building potential markets in the global technological value chain through utilizing the aggregate knowledge capital derived from semiconductor technologies [29]. LED is realized as one of the niches from a diverse range of semiconductor technological innovations. For energy efficiency processes, we conjecture that the concerted efforts of these economies are attributed to their governments ensuring that the industrial development is consistently reinforced with innovations in energy efficiency and conservation in order to achieve sustainable development [11].

4.2 Revealed Technological Advantage

Table 2 compares China and ASEAN-4 member economies in 22 low carbon energy technologies in term of RTA measures in three periods of time, i.e. 2000, 2005 and 2010. We measure the variation of the RTA (CV) by deriving the coefficient between the standard deviation and the mean of RTA values to determine whether an economy has targeted niches of technological excellence (relatively high CV) or diversified its competence to a wide spectrum of specialization (relatively low CV).

In Table 2, we noted that both China and ASEAN economies have not only advanced their technological advantage in number of low carbon energy technologies over a 10 year period, but also attained better positions in terms of the number of RTAs above unity (7 and 11 respectively in 2010). The ASEAN economies appear to have achieved a critical mass of technological competencies (11 over 22 technologies with RTA>1 in 2010). China has, on the other hand, attained lower value of CV compared to ASEAN economies. It is seems that China has attempted to broaden its competencies to a wider spectrum of areas to support the growing domestic market demand for low carbon energy technological innovations.

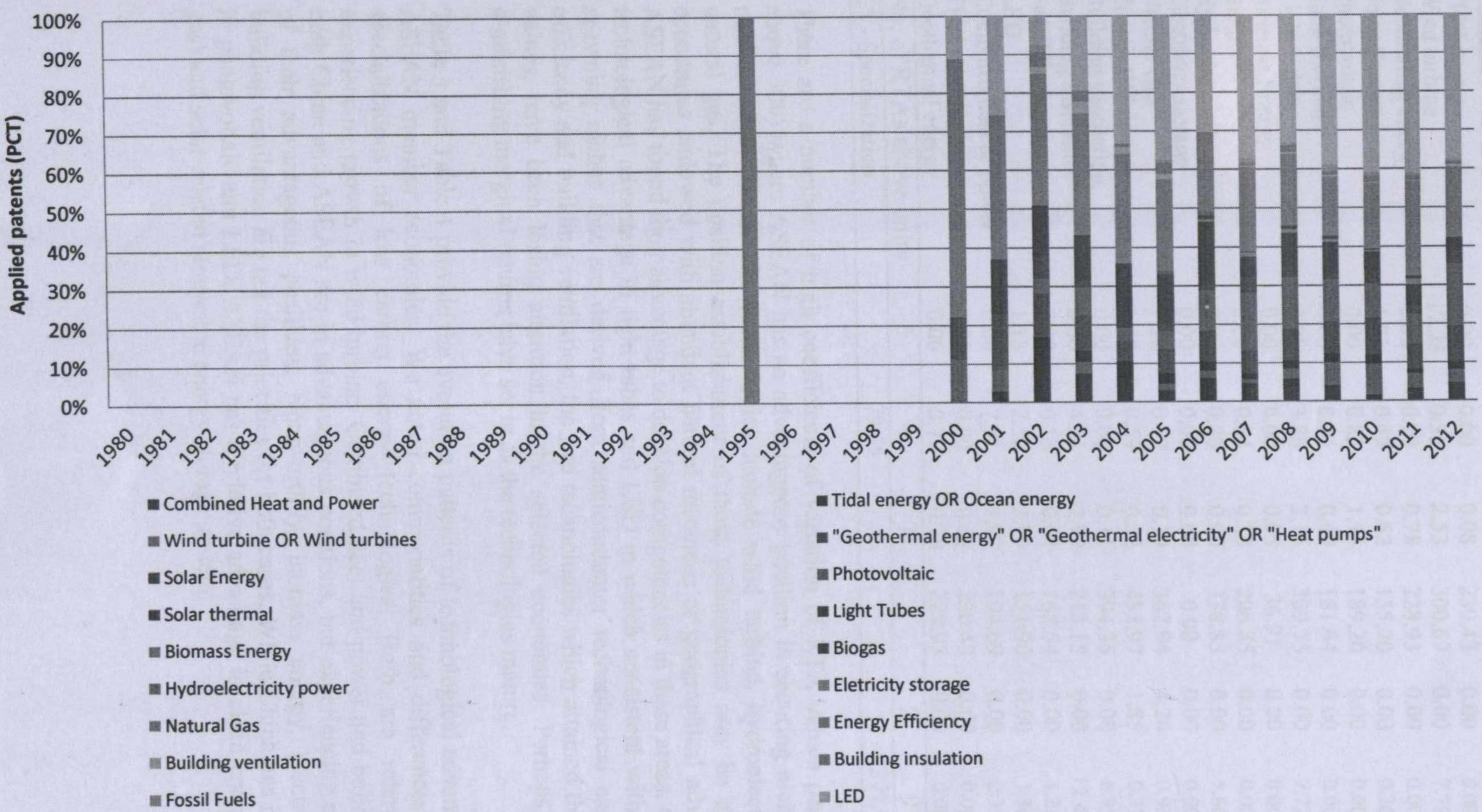

Figure 3: The Share of Applied Patents for the Selected Economies by Field of Low Carbon Energy Technologies

Table 2: RTA in Selected Economies

	China				ASEAN-4			
	2000	2005	2010	CV	2000	2005	2010	CV
Combined heat & power	0.00	7.51	1.93	194.69	0.00	2.39	1.50	314.16
Tidal energy	0.00	0.00	0.08	230.43	0.00	0.00	0.24	393.10
Wind turbine	17.28	0.35	2.53	300.69	0.00	7.78	8.39	218.62
Geothermal energy	0.00	0.79	0.78	228.93	0.00	0.00	0.46	412.44
Solar Energy	1.01	0.49	0.62	155.70	0.00	0.26	1.09	274.55
Photovoltaic	0.00	0.82	1.13	189.20	0.00	0.00	0.85	326.76
Solar thermal	0.00	0.34	0.49	181.64	0.00	0.00	1.13	318.36
Light Tubes	0.00	3.86	3.16	309.75	0.00	7.72	1.50	573.40
Biomass Energy	0.00	0.00	0.05	36.91	0.00	0.00	0.00	0
Biogas	0.00	0.84	0.23	206.85	0.00	0.00	0.33	338.86
Hydroelectricity power	0.00	0.80	0.00	338.83	0.00	5.86	1.07	560.04
Electricity storage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Natural Gas	1.22	0.59	0.19	362.94	4.26	0.93	1.41	617.94
Energy Efficiency	1.58	0.59	0.52	452.97	1.85	0.37	0.39	825.33
Building ventilation	0.00	0.00	0.11	394.35	0.00	8.95	0.67	719.71
Building insulation	0.00	4.24	2.79	213.15	0.00	12.45	4.21	375.18
Fossil Fuels	0.00	0.16	0.04	168.54	0.00	1.21	1.25	260.65
LED	1.13	2.50	3.79	151.90	0.00	1.36	1.21	273.78
Combined heat & power	0.00	7.51	1.93	194.69	0.00	2.39	1.50	377.94
Tidal energy	0.00	0.00	0.08	230.43	0.00	0.00	0.24	314.16
Geothermal energy	0.00	0.79	0.78	228.93	0.00	0.00	0.46	393.10
No. of RTAs above unity	5	4	7		2	9	11	
CV- Specialization		79.55				377.94		

There are a number of high coefficients of variation of RTA values per technology (CV above 300) where ASEAN has an advantageous position in securing niches from potential market value chains. The technologies include wind turbine, hydroelectricity power and natural gas. The position establishment of these technologies may be attributed to those economies endowed with abundant natural resources or geographical advantages in which ASEAN has found their advantage to develop competencies in these areas. China has a strong technological advantage in light tubes and LED in which consistent with its active role in spawning niches that are derived from semiconductor technological capabilities. Energy efficiency and building ventilation, the two technologies which attained the two highest CV values, have been losing attention in the selected economies. Perhaps some aspects of diminishing marginal returns have set in as the technologies mature.

Table 3 and Table 4 provide the evolution patterns of technological advantage of China and ASEAN member economies. We noted commonalities and differences in the scope of specializations of low carbon energy technologies. Both are relatively strong and experiencing growth in wind turbine. Combined heat and power and building insulation for both China and ASEAN are in advantageous positions, but experiencing contracting growth of their advantageous positions. Noteworthily, biomass energy, electricity storage and building ventilation are not the priorities for both cases. While China has increasing strength in photovoltaic and LED, ASEAN has a relative advantage in clean energy source (natural gas) and solar-related renewable energy storage system.

Table 3: The Evolution of Technological Advantage of China, 2005-2010

	Increasing	Marginal Change/Stable	Decreasing
Advantage (RTA>1)	Wind turbine Solar energy Solar thermal Natural gas	Fossil fuels LED	Combined heat & power Light tube Hydroelectricity power Building insulation
Disadvantage (RTA<1)	Tidal energy Geothermal energy Photovoltaic Biogas	Biomass energy Energy efficiency Building ventilation Electricity storage	

Figure 4 shows the technological maps of China. We noted that China is in a leading position for a number of low carbon energy related technologies. Combined heat and power, wind turbine, photovoltaic, light tubes, building insulation and LED have emerged as leading technologies which might provide China with a dominant position in global market value chains. The scatter plot for China appears to suggest a positive linear relationship. While there are six technologies moving ahead, many others are scattered in the lagging behind quadrant. Geothermal, solar energy, solar thermal and energy efficiency are the technologies that have lost the momentum of gaining comparative advantage over other economies.

Table 4: The Evolution of Technological Advantage of ASEAN, 2005-2010

	Increasing	Marginal Change/Stable	Decreasing
Advantage (RTA>1)	Wind turbine Photovoltaic LED	Light tube	Combined heat & power Building insulation
Disadvantage (RTA<1)	Tidal energy Solar thermal Solar energy	Biomass energy Biogas Hydroelectricity power Electricity storage Natural gas Energy efficiency Building ventilation Geothermal energy	Fossil fuels

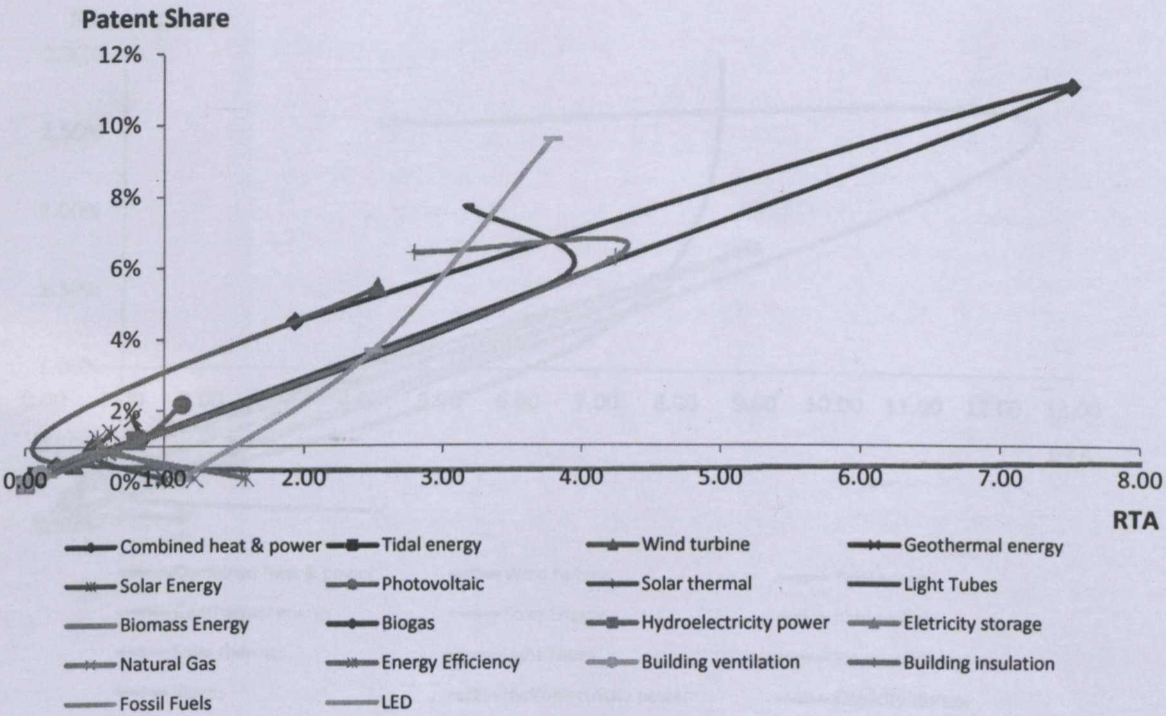

Figure 4: Technology Map of China, 2000, 2005 and 2010

For the case of ASEAN economies (Figure 5), we observed that many technologies were oriented towards niches of technological excellence and only two (building insulation and wind turbine) were targeted to compete in the leading ahead quadrant. LED, fossil fuels, building insulation, natural gas, hydroelectricity power, light tubes, solar thermal and solar energy emerged to be the niches for ASEAN economies. It would be of interest to explore the position of Malaysia's technologies (see Figure 6) to reflect the overall evolution pattern of ASEAN's development in low carbon energy technologies. We observed that many technologies of Malaysia have evolved from lagging behind quadrant to niche quadrant. In addition, light tubes – a technology which had used to provide Malaysia with a leading position in the global value chain – has moved to niche position to target specific consumers' needs, instead of a wider spectrum of consumers in the global market chain. In the context of Malaysia, the government could have regarded these technologies as the targeted areas that might generate economic value to the market and society. A combination of techno-entrepreneurial infrastructure that would stimulate the interests of techno-entrepreneurs in these technologies, and a supply of engineers who are capable of exploiting the market opportunities of these technologies is crucial for successful economic catching-up of Malaysia.

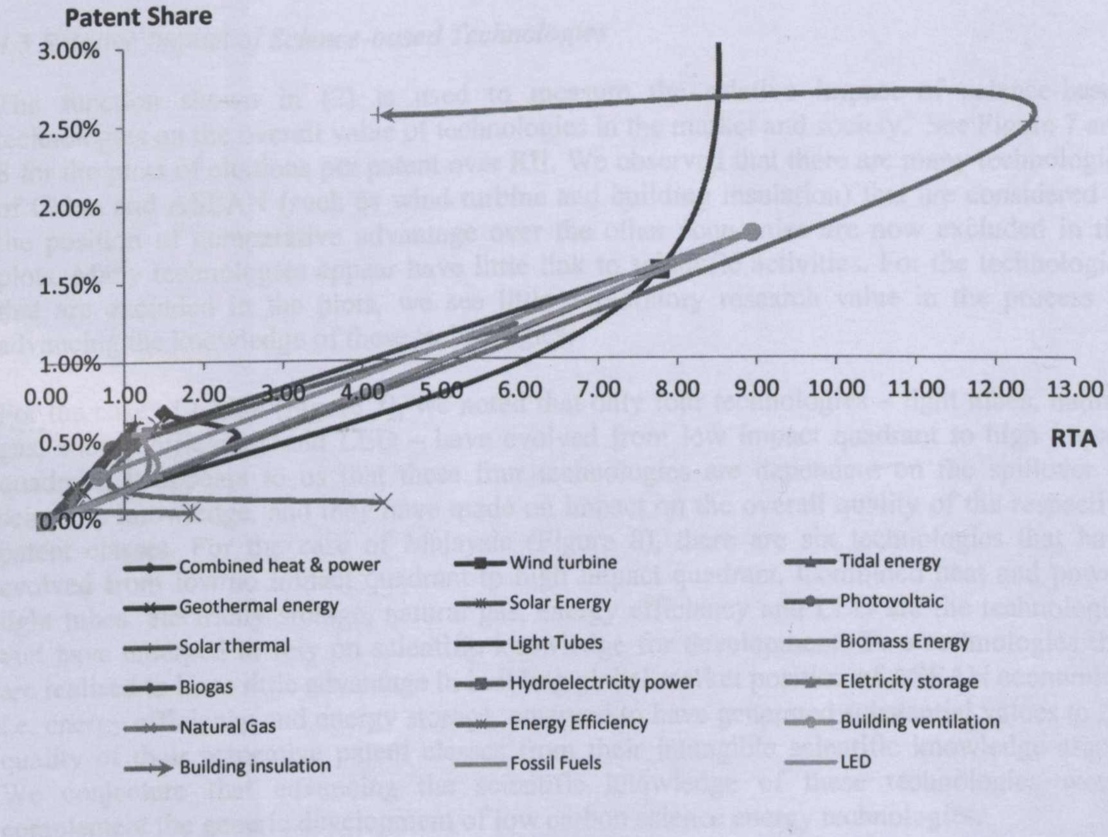

Figure 5: Technology Map of ASEAN Economies, 2000, 2005 and 2010

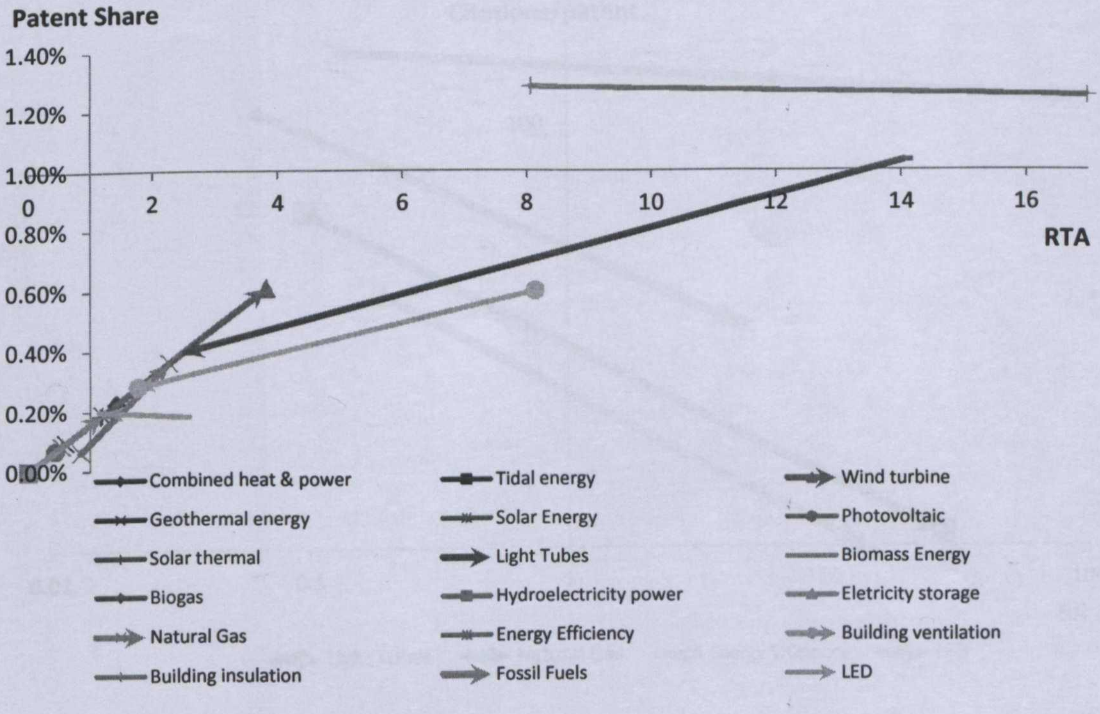

Figure 6: Technology Map of Malaysia, 2005 and 2010

4.3 Relative Impact of Science-based Technologies

The function shown in (2) is used to measure the relative impact of science-based technologies on the overall value of technologies in the market and society. See Figure 7 and 8 for the plots of citations per patent over RII. We observed that there are many technologies of China and ASEAN (such as wind turbine and building insulation) that are considered in the position of comparative advantage over the other economies are now excluded in the plots. Many technologies appear have little link to scientific activities. For the technologies that are excluded in the plots, we see little exploratory research value in the process of advancing the knowledge of these technologies.

For the case of China (Figure 7), we noted that only four technologies – light tubes, natural gas, energy efficiency and LED – have evolved from low impact quadrant to high impact quadrant. It appears to us that these four technologies are dependent on the spillover of scientific knowledge, and they have made on impact on the overall quality of the respective patent classes. For the case of Malaysia (Figure 8), there are six technologies that have evolved from low/no impact quadrant to high impact quadrant. Combined heat and power, light tubes, electricity storage, natural gas, energy efficiency and LED are the technologies that have emerged to rely on scientific knowledge for development. Two technologies that are realised to have little advantage in building global market position of ASEAN economies, i.e. energy efficiency and energy storage, emerged to have generated substantial values to the quality of their respective patent classes from their intangible scientific knowledge assets. We conjecture that advancing the scientific knowledge of these technologies would complement the generic development of low carbon science energy technologies.

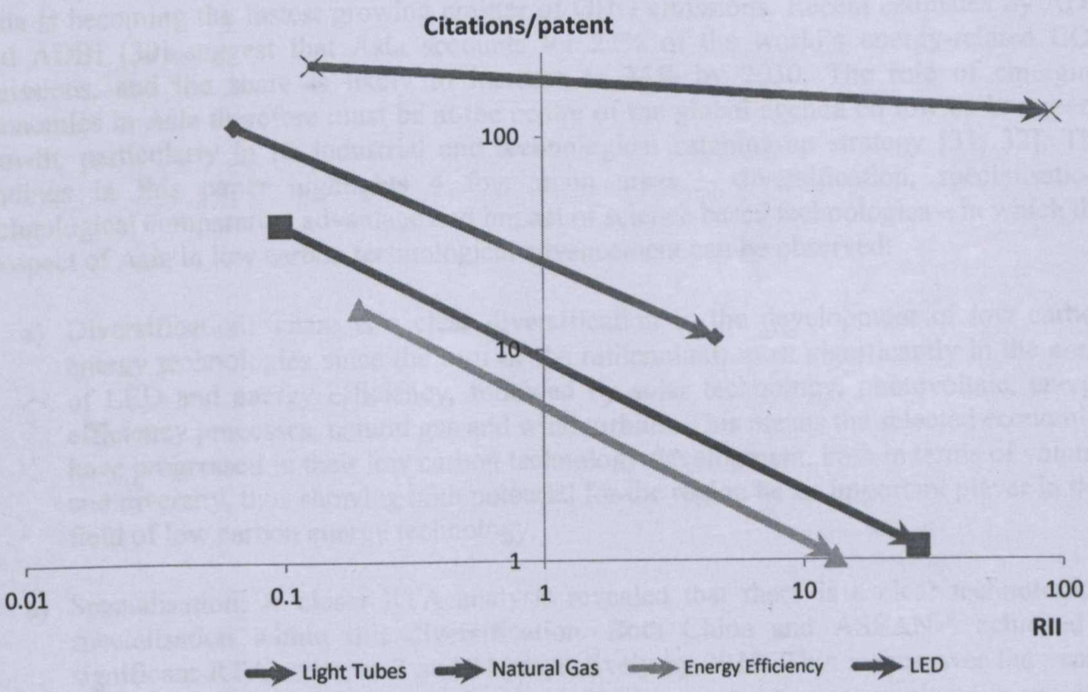

Figure 7: Relative Impact Map of China, 2005-2010

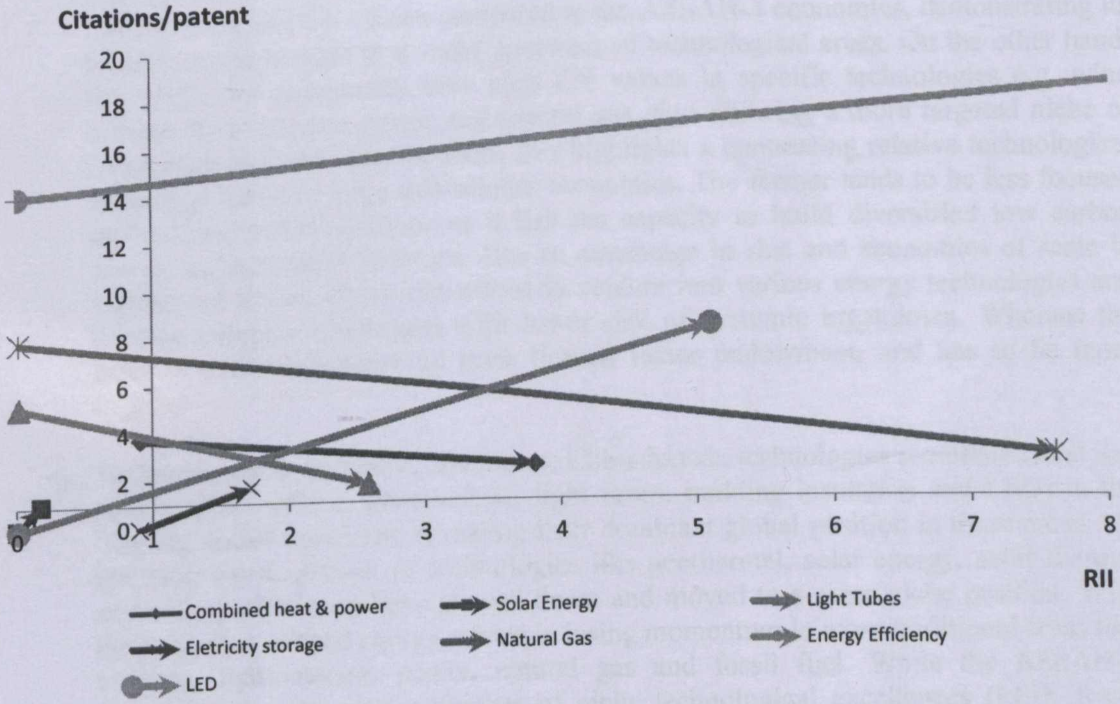

Figure 8: Relative Impact Map of ASEAN, 2005-2010

5. Conclusion

Asia is becoming the fastest growing emitter of GHG emissions. Recent estimates by ADB and ADBI [30] suggest that Asia accounts for 27% of the world's energy-related CO2 emissions, and the share is likely to increase to 44% by 2030. The role of emerging economies in Asia therefore must be at the centre of the global agenda on low carbon green growth, particularly in its industrial and technological catching-up strategy [31, 32]. The findings in this paper highlights 4 four main areas – diversification, specialisation, technological comparative advantage and impact of science based technologies – in which the prospect of Asia in low carbon technological advancement can be observed:

a) Diversification: There is a clear diversification in the development of low carbon energy technologies since the turn of the millennium, most significantly in the areas of LED and energy efficiency, followed by solar technology, photovoltaic, energy efficiency processes, natural gas and wind turbine. This means the selected economies have progressed in their low carbon technology development, both in terms of volume and diversity, thus showing high potential for the region be an important player in this field of low carbon energy technology.

b) Specialisation: A closer RTA analysis revealed that there is a clear technological specialisation within this diversification. Both China and ASEAN-4 achieved a significant RTA score, at 7 and 11 respectively by 2010. This means over the years, there has been a critical mass of technological competencies accumulated in specific areas that can be strategically exploited. China has a relative advantage in photovoltaic and LED, while ASEAN-4 has a relative advantage in solar energy, solar thermal and natural gas. Both share high potential in wind turbine. However, China has lower overall CV values compared to the ASEAN-4 economies, demonstrating its broader competencies in a wider spectrum of technological areas. On the other hand, the ASEAN-4 economies have high CV values in specific technologies e.g. wind turbine, hydroelectric power and natural gas, thus showing a more targeted niche of technological excellence. In short, this highlights a contrasting relative technological advantage between large and smaller economies. The former tends to be less focused on building niche positions as it has the capacity to build diversified low carbon energy technological structure. Due to advantage in size and economies of scale in various industries, China can afford to venture into various energy technologies and manage complex challenges with lower risk of systemic breakdown. Whereas the latter is more dependent on their limited factor endowment, and has to be more targeted.

c) Technological comparative advantage: China has six technologies (combined heat and power, wind turbine, photovoltaic, light tubes, building insulation and LED) in the 'leading ahead' quadrant, revealing their dominant global position in these areas. On the other hand, growth of technologies like geothermal, solar energy, solar thermal and energy efficiency have slowed down and moved to a more niche position. With the exception of tidal energy, China is losing momentum in more traditional areas like biomass, hydroelectric power, natural gas and fossil fuel. While the ASEAN-4 economies are showing a number of niche technological excellences (LED, fossil fuel, building insulation, natural gas, hydroelectric power, light tubes, solar thermal, solar energy), only two technologies (building insulation and wind turbine) are in the leading ahead quadrant. They are lagging behind in both traditional and new areas (biomass energy, geothermal, photovoltaic, geothermal energy, electricity storage, energy efficiency, building ventilation). This mapping of technological comparative advantage draws attention to the existing technological strengths of the economies that should be maintained and enhanced, plus areas of losing momentum and lagging behind that can be improved, re-evaluated or even terminated.

d) Impact of science-based technologies: The profile of technological advantage however does not coincide with the impact of science-based technologies. Most of the technologies observed have little link to scientific activities. However there are exceptions. In the case of China, four technologies (light tubes, natural gas, energy efficiency and LED) have evolved from low impact quadrant to high impact quadrant. Except for natural gas, these coincide with areas in which China is leading ahead technologically. For ASEAN-4, impact of science to areas like energy efficiency and energy storage is relatively high, but these are the exact technological areas in which the economies are lagging behind. Such findings point to the interesting fact that the development of low carbon technologies in Asia may not have strong scientific grounding as yet, except for limited areas of technology. It also leads to the question on how far investments in low carbon R&D in Asia are paying off [30], and in what ways can they be improved. China in this instance seems to be performing better than the ASEAN-4 economies.

From these findings, we can conclude that evidence from China and ASEAN-4 has shown that emerging economies in Asia have the potential to be significant players in the growing low carbon energy industry, not only in terms of volume but also growing diversification and specialisation of technologies. We also highlighted that the economies have the propensity to play out different strategies in their low carbon technological development – be it niche or broad based – depending on their path dependency and factor endowments. A closer analysis on such comparative advantage can be a way forward to synergise efforts and increase strategic collaboration for low carbon energy development in the region.

However, China's aggressive low carbon strategy has resulted in better positioning in terms of technological comparative advantage and harnessing the impact of science-based technologies. This is in line with the trends observed by Yuan et al [33] that China's 45% CO_2 intensity reduction target by 2020 is not only within international expectations, but also consistent with the country's economic and social development strategy. China is also forging ahead in the development of science-based technologies in the areas of LED, light tubes and energy efficiency. On the other hand, ASEAN-4 is performing less effectively – none of their strengths in science-based technologies has contributed to their technological comparative advantage. Nevertheless, the findings as a whole have shown that science-based technologies have very little impact in overall technological competitiveness in both China and ASEAN-4. This opens up the question of the effectiveness of STI policies in the region, especially on how much R&D efforts and investments [30] are supporting long-term competitiveness in low carbon energy technologies.

References

[1] Mathews, J. and Cho, D-S., Tiger Technology: The Creation of a Semiconductor Industry in East Asia, Cambridge: Cambridge University Press, 2000.

[2] D. Angel and M.T. Rock, Environmental Rationalities and the Development State in East Asia: Prospects for a Sustainability Transition, Technological Forecasting and Social Change, 2009, 76 (2), 229-240.

[3] J. A. Schumpeter, The Theory of Economic Development, Harvard University Press, Cambridge, 1934.

[4] M. Bell and K. Pavitt, Technological Accumulation and Industrial Growth: Contrasts Between Developed and Developing Countries, Industrial and Corporate Change, 1993, 2 (2), 157-210.

[5] P. Patel and K. Pavitt, Uneven (and Divergent) Technological Accumulation among Advanced Countries: Evidence and a Framework of Explanation, Industrial and Corporate Change, 1994, 3(3), 759-787.

[6] L. Nesta and P. Patel, National Patterns of Technological Accumulation: Use of Patent Statistics, in H.F. Moed, W. Glanzel and U. Schmoch (Ed.), Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems, Kluwer Academic Publisher: New York, 2005, 531-552.

[7] S. Lall, India's Manufactured Exports: Comparative Structure and Prospects, World Development, 1999, 27(10), 1967-1786.

[8] S. Lall and M. Albaladejo, China's Competitive Performance: A Threat to East Asian Manufactured Exports?, World Development, 2004, 32(9), 1441-1466.

[9] C-Y. Wong, G. Siow, R. Li and K-T. Kwek, The Impact of China on the Emerging World: New Growth Patterns in Chinese Import-Export Activities, Inzinerine Ekonomika-Engineering Economics, 2013, 24(4), 309-319.

[10] K. Lee and S. Lee, Patterns of Technological Innovation and Evolution in the Energy Sector: A Patent-based Approach, Energy Policy, 2013, 59, 415-432.

[11] C-Y. Wong, Z.F. Mohamad, Z-X. Keng and S.A. Azizan, Examining the Patterns of Innovation in Low Carbon Energy Science and Technology: Publications and Patents of Asian Emerging Economies, Energy Policy, 2014, 73, 789-802.

[12] M. Hobday, Innovation in East Asia: Diversity and Development, Technovation, 1995, 15(2), 55-63.

[13] B. A. Lundvall (Ed.), National Innovation Systems: Towards a Theory of Innovation and Interactive Learning, London: Pinter.

[14] A.B. Jaffe and M. Trajtenberg, International Knowledge Flows: Evidence From Patent Citations, Economics of Innovation and New Technology, 1999, 8, 105–136.

[15] V. Albino, L. Ardito, R.M. Dangelico and A. M. Petrusselli, Understanding the Development Trends of Low-Carbon Energy Technologies: A Patent Analysis, Applied Energy, 2014, In Press.

[16] H. Choe, D.H. Lee, I.W. Seo and H.D. Kim, Patent Citation Network Analysis for the Domain of Organic Photovoltaic Cells: Country, Institution, and Technology Field, Renewable and Sustainable Energy Reviews, 2013, 26 492–505.

[17] L. Duan, Analysis of the Relationship between International Cooperation and Scientific Publications in Energy R&D in China , Applied Energy, 2011, 88, 4229–4238.

[18] B. Li, Y. Duan, D. Luebke and B. Morreale, Advances in CO_2 Capture Technology: A Patent Review, Applied Energy, 2013, 102, 1439-1447.

[19]S.C. Mueller, P.G. Sandner and I.M. Welpe [19], Monitoring Innovation in Electrochemical Energy Storage Technologies: A Patent-based Approach, Applied Energy, 2014, In Press.

[20] J. Wonglimpiyarat, Technological Change of the Energy Innovation System: From Oil-based to Bio-based Energy, Applied Energy, 2010, 87, 749-755.

[21] T.D. Corsatae, Technological Capabilities for Innovation Activities across Europe: Evidence from Wind, Solar and Bio-energy Technologies, Renewable and Sustainable Energy Reviews, 2014, 37, pp. 469-479.

[22] T. Altenburg and T. Engelmeier, Boosting Solar Investment with Limited Subsidies: Rent Management and Policy Learning in India, Energy Policy, 2013, 59, pp. 866-874.

[23] J. Schot and F.W. Geels, Strategic Niche Management and Sustainable Innovation Journeys: Theory, Findings, Research Agenda and Policy, Technology Analysis and Strategic Management, 2008, 20, pp. 537-554.

[24] J. Nill and R. Kemp, Evolutionary Approaches for Sustainable Innovation Policies: From Niche to Paradigm, Research Policy, 2009, 38, pp. 668-680.

[25] S. Lee, H. Lee and B. Yoon, Modeling and Analyzing Technology Innovation in the Energy Sector: Patent-based HMM Approach, Computers and Industrial Engineering, 2012, 63, pp. 564-577.

[26] K. Pavitt, International Patterns of Technological Accumulation, In N. Hood, J.E. Vahlne (Ed.), Strategic in Global Competition, Helm: London, 126-157.

[27] N. Islam and K. Miyazaki, An Empirical Analysis of Nanotechnology Research Domains, Technovation, 2010, 30(4), 229-237.

[28] B. Asgari, and C-Y. Wong, Depicting the Technology and Economic Development of Modern Malaysia, ASIAN Journal of Technology Innovation, 2007, 15 (1), 167-193.

[29] C-Y. Wong and K-L. Goh, The Pathway of Development, Science and Technology of NIEs and Selected Asian Emerging Economics, Scientometrics, 2012, 92(3), 523-548.

[30] Asian Development Bank (ADB) and Asian Development Bank (ADBI), Low-Carbon Green Growth in Asia Policies and Practices, ADBI, Hong Kong, 2013.

[31] UNESCAP, Low Carbon Green Growth Roadmap for Asia and the Pacific: Turning resource constraints and the climate crisis into economic growth opportunities, Bangkok, United Nations Publication, 2012.

[32] Berkhout. B, Verbong. G, Wieczorek. A. J., Raven. R, Lebel. L. Bai, X., Sustainability experiments in Asia: innovations shaping alternative development pathways?, Environmental Science & Policy, 2010, 13(4), 261-271

[33] Yuan. J, Hou. H, Xu. Ming, China's 2020 Carbon Intensity Target: Consistency, Implementations, and Policy Implications, Renewable and Sustainable Energy Reviews, 2012, 16(7), 4970–4981.